A Study on the Implementation of the Strengthening Innovation and Practice in Secondary Education Initiative for the preparation of Science, Technology, English and Mathematics (STEM) Teachers in Kenya to integrate Information and Communication Technology (ICT) in Teaching and Learning

Hooker, Mary

Award date:
2017

Awarding institution:
Queen's University Belfast

A Study on the Implementation of the *Strengthening Innovation and Practice in Secondary Education Initiative* for the preparation of Science, Technology, English and Mathematics (STEM) Teachers in Kenya to integrate Information and Communication Technology (ICT) in Teaching and Learning

Mary Hooker

Dissertation submitted in partial fulfilment for the degree of
Doctor in Education (Ed.D)
in the
School of Social Sciences, Education and Social Work
Queen's University Belfast

May 2017

ABSTRACT

The *Strengthening Innovative Practice in Secondary Education (SIPSE)* project was conceptualized to enhance teacher capacity in ICT competencies and skills to teach Science, Technology, English and Mathematics (STEM) subjects in Kenya secondary schools. The aim of this research study was to critically appraise the innovation model in relation to teacher development for ICT use in classroom practice associated with the SIPSE project over two cycles of the pilot phase implementation. The model integrated an ICT Competency Framework for Teachers (ICT-CFT) and Technology Pedagogy and Content Knowledge (TPACK) frameworks into a phased modular approach (ICT-CFT-TPACK-in-practice) for teacher professional development. The research addressed key questions related to: the object of ICT use as perceived by head teachers and teachers; and the characteristics of teacher design for ICT use in STEM teaching and learning as evidenced in classroom activities at different stages of their professional learning journey in the SIPSE intervention. The study used a qualitative design based research (DBR) methodology that was enhanced with the use of a 'TPACKtivity' lens combining TPACK and Activity Theory (AT) to explore, explicate and communicate the findings. The study was conducted with a purposive sample of twenty-four teachers, four head teachers and four schools drawn from the wider SIPSE programme intervention. The research data was collected over three field visits carried out between September 2014 and February 2016. The qualitative research methods included individual interviews and focus group discussions with the teachers and the head teachers. Data were also drawn from documentation of lesson plans and peer-to-peer lesson observations. The findings were illuminating. They presented participant accounts of tensions and dissonances with the introduction of technology into their school and classroom practices that reflected similar issues revealed in the literature. However, the findings elucidated some nuanced shifts and unexpected teacher design narratives for technology use to support, improve and innovate STEM teaching and learning processes. They further revealed the importance of classroom processes as the centre stage for fostering teacher collective and continual design conversations for framing and reframing ICT use solutions appropriate to the affordances and realities of their classroom and school contexts. In this the findings contribute to the current discourse by offering a TPACKtivity framework centred on authentic classroom settings as a basis for developing and appraising models of professional development for ICT use that can inform practice, policy and research.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGEMENTS

I wish to pay special thanks and tribute to my supervisor Dr. Ruth Jarman, for her dedicated support and direction. Her detailed and timely feedback, encouragement and clarity have been an inspiration and a motivation for me through each and every phase of the research. Most of all Dr. Jarman has been a wonderful teacher whether face-to-face or at a distance – providing me with the space to learn, to understand and to explore the nuts and bolts as well as the craft of carrying out a full-bodied research project as in this thesis – it's been a tough and wonderful professional learning journey and experience.

I want to thank my second supervisor Dr. Katrina Lloyd for her guidance, time and timely review and inputs. My thanks also goes to the examiners, external examiner Professor Don Passey, Lancaster University, and internal examiner Dr. Pamela Cowan, Queen's University Belfast, for a critical and stimulating viva-voce and for their review and guidance to assist me in refining the thesis.

I want to thank my organization the Global E-Schools and Communities Initiative, the CEO Mr. Jerome Morrissey and the Director of Programmes, Dr. Patti Swarts for providing permission and the opportunity to conduct this research and for their support and scaffolding of research as a critical pillar in our organizational work.

I would like to thank the National Commission for Science, Technology and Innovation, Kenya for granting the license to conduct the research. My thanks to Professor Olive Mugenda, Kenyatta University, Nairobi, who approved my affiliation to KU so as to carry out the research in Kenya. My thanks to Ms. Esther Muiru and Ms. Helen Kiilu, Directors of Education for Nakuru and Machakos counties respectively, for granting permission and assistance to liaise with the schools for conducting the research.

I want to give my special thanks to the school heads and teachers who participated in this study. The research would not have been possible without them and without their professional dedication, commitment and willingness to contribute to the research discourse.

I want to thank my beloved family Alan, Sara (and her beloved husband Alex), Rose and Sean for their love and support. In particular, I want to thank my husband Alan for his endless patience and encouragement and for putting up with my endless reflections, doubts and musings as the research took hold. It is done and I am back.

CHAPTER 1

Introduction and Overview

1.0 Introduction

The organization that the researcher works for is called the Global e-Schools and Communities Initiative (GESCI).[1] In January 2014 GESCI launched an African regional initiative called the Strengthening Innovation and Practice in Secondary Education (SIPSE) programme. The purpose was to explore innovative uses of technology to deliver and enrich Science, Technology, English and Mathematics (STEM) teaching and learning in secondary schools in Kenya and Tanzania. The SIPSE initiative represented a formal partnership between GESCI and the MasterCard Foundation and a strategic partnership with the Ministries of Education in Kenya and Tanzania to develop a technology-based teacher professional development model for secondary level teachers.[2] The present study focuses on the application of the SIPSE intervention in a sample of four of the SIPSE programme schools in Kenya and constitutes a separate study from the wider programme implementation and evaluation in Kenya and Tanzania.

In this regard, it is important to clarify the research and development roles of the researcher. As a Senior Education Specialist in the GESCI organization, the researcher was involved in the SIPSE project development activities covering country situational and needs assessment, the conceptualization of the SIPSE model design intervention and the design and development of the modular coursework. In her doctrinal research role, the researcher was involved in conceptualizing and implementing a research design to investigate and appraise the impact of the SIPSE model in the sample of schools in Kenya – a design that was separate to and independent of the wider SIPSE programme activities. The research involved collaborative activities between the researcher and participants in the sample schools in appraising the SIPSE model in practice and in identifying design solutions and adjustments that would contribute to future model development. The researcher dual roles, the position of the researcher 'self' in the research processes and the potential constraints and opportunities therein are elaborated in more detail in the main study and more specifically in the research methodology in chapter three.

[1] Global e-Schools and Communities Initiative (2013) Home page.
[2] MasterCard Foundation (2013) Youth Learning: Develop a technology-based teacher training model

1.1 The Context of the Research Inquiry

1.1.1 Institutional Context - GESCI

GESCI is an International Non-Government Organization (INGO) set up under the auspices of a United Nations (UN) Information and Communication Technology (ICT) Task Force in 2004. Its mandate was to assist governments in the socio-economic development of their countries through the widespread integration of technology for inclusive and sustainable knowledge society development (GESCI, 2016). GESCI believes that its foundation mandate has been and continues to be relevant in the context of the UN (2002, 2015) education agendas integral to the pre- and post-2015 development goals (Millennium Development Goals - MDGs; Sustainable Development Goals - SDGs). The success of Education for All (EFA) and Universal Primary Completion (UPC) policies integral to the MDGs have brought to the fore new challenges in low and middle income countries (LMICs) - where increasing numbers of basic education graduates are faced with limited opportunities for further education and steep rises in unemployment for those entering the workplace (UNESCO, 2012).

It is in this context that GESCI has engaged in pilot initiatives such as SIPSE in Kenya and Tanzania. The rationale is to provide case studies, models and evaluation research that will contribute to national systemic frameworks for ICT integration in education and training and align to national development agendas towards sustainable knowledge-based economies and societies.

1.1.2 Country Context - Kenya

Kenya is located in Eastern Africa with a border on the Indian Ocean. The country occupies a landmass of 569,250 km^2 with a population of 46 million and an annual population growth rate of 1.9% (Kenya Open Data, 2015; CIA, 2016). Kenya is working towards becoming a knowledge-based economy and society by implementing its Vision 2030 for social, cultural, political and economic development (GoK, 2008). The country has recently achieved middle income status where agriculture, tourism, manufacturing industry and investment and growth in the rapidly expanding telecommunications sector have been the mainstay and drivers of its economic base – making Kenya the ninth largest economy on the continent (Copley, 2014). Education and training lie at the heart of the national vision and development agenda and are seen as the core strategy for building human resources necessary for employment and wealth creation (Swarts & Wachira, 2009). The country has developed a national educational ICT policy and strategy (GoK, MoE, 2006) in which the role of technology is seen as one that 'provides capabilities and skills needed for a knowledge-based economy', a role that calls for 'transforming teaching and learning to incorporate new pedagogies that are appropriate for the 21st century' (p4).

In this scenario Engeström *et al*. (2014) would suggest that Kenya like many countries and regions, is pushing schools as vehicles for socio-economic development through utilizing the potential of ICTs. What is needed when engaging with partner countries such as Kenya are frameworks and tools that can align partnership interventions into national vision and strategy for building ICT-enabled innovation systematically into education provision.

1.1.3 Intervention Context - SIPSE

The SIPSE programme was conceptualized to enhance teacher capacity in ICT use to teach Science, Technology, English and Mathematics (STEM) subjects in secondary schools. The programme was designed to use blended learning methodologies to build the capacity of twelve teacher educators and sixty secondary STEM school teachers from twenty schools across Kenya and Tanzania. The programme design integrated and contextualized globally benchmarked standards and frameworks for ICT use in teacher development and classroom practice inclusive of the UNESCO (2008, 2011) ICT Teacher Competency Framework for Teachers (ICT-CFT) and Mishra and Koehler's (2006) Technology, Pedagogy and Content Knowledge (TPACK) framework. These combined frameworks defined a *professional development path* for implementing two cycles of the SIPSE intervention from *ICT application* (technology literacy) to *ICT infusion* (knowledge deepening) in STEM classroom practices. The research inquiry design added an Activity Theory (AT) framework (Vygotsky 1978; Engeström 2001, 2003) to track changes in teachers' perceptions, beliefs and attitude towards technology use in STEM as they progressed through the SIPSE professional development cycles.

1.2 Significance of this Study

The significance of this study can be summarized as twofold. Firstly the focus of the research on the SIPSE programme in Kenya is a particularly timely intervention that is positioned to contribute to national systemic frameworks for ICT integration – at a time when the Government of Kenya is embarking on mass deployments of ICT in primary and secondary schools. Such research into the SIPSE model of intervention can advise educational policymakers and stakeholders on future paths for ICT-enabled educational innovation from national to local levels – from policy formulation to classroom practice.

Secondly there is an apparent need for deeper research in the area of teacher education for effective ICT integration in schools and classroom practice (Schmidt et al., 2009; McDonough and Le Baron, 2010; Lee & Tsai, 2011; Jaipal-Jamaini & Figg, 2015). The issues of what teachers need to know and be able to do to integrate technology effectively are highly important for informing policy and practice in teacher education. It is hoped that the research will contribute to the knowledge field in general. In a broader context it is hoped that the contribution might have what Hammond (2013) describes as a 'value for use' factor – that is that the research provides useful, usable and relatable knowledge to policy makers, educators, practitioners and researchers affiliated to ICT in education and teacher education.

1.3 Aims and Objectives

The aim of this research study is to critically appraise the innovation model in relation to teacher development for ICT use in classroom practice associated with the Strengthening Innovation and Practice in Secondary Education (SIPSE) programme over the two cycles of its pilot phase implementation. The research study centres on a purposive sample of twenty four teachers and four school heads from four of the SIPSE pilot project schools in Kenya. The key objectives are to track the object of participant perceptions and understandings of ICT use in STEM classroom practices over the two cycles of the programme intervention; and to investigate how teachers' perceptions and practices in applying ICT evolve during their professional learning journey.

Following an extensive review of the extant literature which included an examination of the context of ICT, STEM and teaching and learning in the changing landscapes of global and African agendas for sustainable development towards knowledge societies, combined with an analysis of theoretical and conceptual lenses for examining ICT use in teacher education and the STEM curriculum, the following research questions were developed:

1. What is the object of ICT integration perceived by head teachers and teachers during the two cycles of the SIPSE pilot programme?
2. What are the characteristics of teacher design for ICT use in STEM teaching and learning mid-way through the SIPSE pilot programme, as evidenced in their approach to problem-based activities?
3. What are the characteristics of teacher design for ICT use in STEM teaching and learning at the end of the SIPSE pilot programme, as evidenced in their approach to project-based activities?

1.4 Some Key Definitions

The essence of the SIPSE pilot programme is about teacher professional development (TPD) to support effective ICT use in STEM classroom practice. While there are many interpretations of what ICT, TPD, STEM, competencies and innovation are, there are no commonly accepted definitions. Table I presents a set of definitions that together bring out a holistic view of key terminologies in this study and how they will be interpreted while recognizing the broader scope for their application.

Table I - Definitions and Terminologies

Terminologies	Definitions
Information and Communication Technology (ICT)	ICT refers to the **range of technologies** that are applied in the process of collecting, storing, editing, retrieving and transfer of information in various forms (Olakulehin, 2007). The Kenya Ministry of Education (2006) outlines **a range of traditional and new technology resources and processes** that though not exhaustive, have been used in the delivery of education to improve access, teaching, learning, and administration, namely: '*electric board, audio cassette, radio for interactive radio instructions (IRI), video/TV-learning, computer, integrated ICT infrastructure and support application systems (SAS), as well as the methods, practices, processes, procedures, concepts and principles that come into play in the conduct of the information and communication activities.' (p 5)*
STEM	In the SIPSE pilot STEM is defined as Science, Technology English and Mathematics (STEM). The Technology focus is on the subject and the **use of technology to enhance innovative practice** in Science, Mathematics and English (SME) subjects.
Technology enhanced teaching and learning	Refers to the use of technologies in teaching and learning environments for any educational purpose (South African Department of Education 2001, cited in Gakuu & Kidombo, 2008)
Teacher Professional Development (TPD)	Teacher development can be defined **as a systematized, initial and continuous, coherent and modular process of professional development of educators** in accordance with professional competency standards and frameworks. Teacher development would also include training in adaptation to the evolution of change of the profession of teachers and managers of education systems (Isaacs, 2006)
ICT Competency Standards	Competence is defined as the **ability to combine and apply relevant attributes** to particular tasks in particular contexts. These attributes include high levels of knowledge, values, skill, personal dispositions, sensitivities and capabilities, and the ability to put those combinations into practice in an appropriate way. An ICT competency describes **what a teacher should know be able to do with technology** in professional practice. An ICT standard is a combination of attributes describing a teacher's professional performance involving the use of ICT (Commonwealth of Australia, Department of Education, Science and Training, 2002)
Innovation in educational practice	Innovation is a **dynamic and unpredictable social process** involving **complex interactions** between various actors who 'actively seek to learn from each other'. Innovation in education has two potential levels**:** A first level describes the **appropriate education and training** necessary for developing and transforming student creative potential into adult innovation and fostering innovation. A second level points to the need for innovation **to improve and transform education and training system provision** in order to effectively meet the needs of 21st century learners (Kampylis *et al*., 2012)
Technology Affordance	An **affordance is an emergent property** of an object. Within the notion of affordance are the subsidiary notions of **opportunity and constraint**.

Terminologies	Definitions
	In the **case of technology** the 'affordances' key stakeholders of teachers, head teachers and students perceive in the technology tool can be a pre-requisite to understanding the potential 'take up' of technology in schools (Hammond, 2010)
Design thinking and teacher design	**Design thinking** underpins intentional acts that can lead to the creation of new products, experiences or services by **optimizing the opportunities and minimizing the constraints of a problem space.** **Teacher design** for ICT use is implicit in sequencing design actions for ICT integration in practice – developing **frames and ideas, designing lessons and materials** to engage students, implementing the lesson and engaging in reflection-in-action (Koh, Chai, Wong and Hong, 2015)

1.5 Dissertation Organization

This dissertation encompasses seven chapters. This chapter outlines the context, significance and aims of the study as well as definitions of some key terms that are linked to the study themes. Chapter two presents a review of the literature in relation to the global agendas that are defining and shaping the use of ICT in education and in teaching and learning. It includes a critical review of the three frameworks of ICT-CFT, TPACK and AT that make up key conceptual elements of the SIPSE programme and research intervention at the heart of the present study.

Chapter three explains the qualitative research strategy and design-based research approach that underpins the study. It provides descriptions of the purposive sampling process for the selection of the research schools, teachers and head teachers, of data collection tools and data analysis processes.

Chapters four, five and six present the research findings and discussion as they relate to each of the research questions. The findings map the tensions, contradictions and opportunities for improving practice that the SIPSE intervention created and the questions therein for design of future models of intervention.

Chapter seven presents the research conclusions outlining the impact of the SIPSE programme design in teacher development for ICT use in STEM classroom practice, the implications for the design of futures models, some possible policy responses that can be considered, the study limitations as well as areas for further research in the field.

CHAPTER 2

Literature Review

2.0 Introduction

The focus in this review is to examine the literature in the ICT teacher education field, to explore some key conceptual frameworks that are defining the field, and to understand the gaps and potential areas for research. The review will consider four main themes related to ICT and its evolution into the mainstream of STEM education and teacher education discourse for sustainable and knowledge society development, as follows:

- Global, Regional and National Agendas driving ICT in STEM Education
- Reconceptualising Teacher Education and ICT Use for a Knowledge Age
- Three Lenses for Examining Teacher Development for ICT Use
- The SIPSE Model for ICT Integration in STEM Classroom Practices

2.1 Global, Regional and National Agendas driving ICT in STEM Education

2.1.1 The ICT in Education Agenda

The world at the beginning of the 21st century has been witness to epochal changes. The globalization and internationalization of economies propelled by an ICT revolution have been key drivers transforming the way in which we live, work and learn (Voogt & Roblin, 2012; Lagaarde, 2014). Kereluik *et al.* (2013) describe the synergies of new technology and globalization as creating economic shifts 'from manual and routine jobs to an intellectual and knowledge economy' that is 'facilitated and accelerated by technological modernisation' (p29). These dramatic shifts have positioned knowledge as the major commodity (over traditional commodities of capital, natural resources and labour) to exert power and influence in national, regional and global socio-economic development (Drucker, 1993; Seldon & Cairns, 2002). As such the present society has been characterized by many as a 'knowledge society' (UNESCO, 2005; Sugrue, 2008; Teräs *et al.,* 2010; Voogt & Roblin, 2012).

Voogt and Pelgrum (2005) describe Knowledge Society new demands on global citizenry to be able to handle, manage and research vast amounts of information with the assistance of Information and Communication Technologies (ICTs). Butler *et al.* (2013) consider the rapid changes in today's workforce, in technology advancements and increasing global competition has meant 'that learning is more critical than ever' (p2). Indeed, there is much literature evaluating the role of educational and training systems as a crucial pillar to provide trained manpower or knowledge workers (engineers, scientists, technicians, craftsmen, artisans) in the quantity and quality needed to address the challenges of the knowledge age workplace and research and development institutes (Bamiro, 2007; Dahlman, 2007; Spring, 2008; Butcher, 2010; Adam *et al.*, 2011; and Tawil, 2012). Hargreaves (2003) analyses critical gaps between knowledge economies and societies stimulated and driven by 'creativity', 'innovation' and 'ingenuity' and schooling systems mired in the regulations of 'soulless standardization' instead of 'promoting economic invention and social integration' (p2).

Voogt and Pelgrum (2005) relate general beliefs in ICT capacity 'to implement and facilitate the realization of the pedagogy that fits an information society' (p159). The literature presents parallel assumptions in the affordances of new technologies to 'impact positively on student performance and heighten student motivation' (Hardman, 2005, p258), to 'prompt a fundamental rethinking of educational purpose and practice' (McDonough & Le Baron, 2010, p21), to create a 'privileged space to reinvigorate the search for the most structuring concepts of school and public education, and also of lifelong learning' (Almeida & Franco, 2013, p192); and as 'one of the most important influences in teacher education programmes' (Cowan, 2011, p1). However, research shows that the implementation of ICT within education systems is a complex process. Power *et al.* (2014) in a literature search of 83 studies discuss findings on large scale investment in technology interventions[3] across education systems north and south 'that produce limited educational outcomes' (p4). Aristovnik (2012) in a study of OECD and EU countries found significant differences in the efficiency of ICT use across the majority of countries while 'most of the countries under consideration [held] great potential for increased efficiency in ICT and for improving their educational outputs and outcomes' (p144).

Issues on the efficacy and effectiveness of ICT interventions are elucidated in studies of system-wide programme initiatives such as the 'Enlaces' programme in Chile – the subject of much scholarly research since its inception almost three decades ago (Trucano, 2017). While the programme has successfully introduced ICT infrastructure and teacher training into the majority of schools at primary and secondary level, research reports suggest tensions in system integration - where ICT was found to be 'not frequently used at school' (Hinostroza *et al.*, 2011, p1360) and where school principals perceived the 'integration of computers into classroom pedagogical practices [as] the most difficult task at the school level' (Sanchez & Salinas, 2008, p1629). A

[3] Technology interventions were clarified as ranging from interactive radio, to classroom video and audio via teachers mobile phones, to student tablets and e-readers, to computer assisted learning

UNESCO study (2013) on ICT use in selected ASEAN country education systems similarly cited contradictions in successful interventions - such as the Republic of Singapore case study described as ‘a global leader in the use of technology in education’. The report identified evidence related to challenges of meaningful change in teaching and learning practices, noting that the ‘use of ICT alone does not necessarily lead to better learning, and advanced technologies can in fact mask low levels of student comprehension’ (p115). Nonetheless, there is gathering evidence in current studies such as the OECD *Programme for International Student Assessment (PISA)* of a positive correlation between moderate ICT use in schools and improved learner achievement in reading, mathematics and science (OECD, 2014, 2015a). There are, however, voices of dissent and caution on the validity of such ‘cause and effect’ correlations given the multiplicity of variables that can impact on school systems and learner achievement (Lim & Hang, 2001; Hammond, 2013; Redecker & Johannessen, 2013).

Jaipal and Figg (2010) contend a general consensus in the literature that effective integration of ICT in school and classroom practices has not been widespread where ‘effective’ would signify technology use to promote ‘meaningful learning’ in subject content (p415). Dreynoyianni (2006) locates issues of meaningful change in a philosophical discussion on contemporary conditions for ICT integration in schools where the process of new technology assimilation ‘mirrors and to a certain degree broadens or exacerbates prevailing socioeconomic problems and current educational conditions’ (p404). Challenges for effective integration have been identified on a spectrum of implementation deficiencies, ranging from: a lack of clarity on vision, policy and leadership (McDonough and Le Baron, 2010); to static schooling organization of space and time manifested in embedded norms of ‘egg crate' classroom arrangements (Asia Society 2015, p15) and 40 minute lesson blocks (Cuban, 2002); to historical and cultural contexts of educational practices embedded in ‘individual and private work’ impeding opportunities for ‘collective collaboration’ (Hannay *et al.,* 2013, p66); to less sophisticated uses of technology to enhance current practice as opposed to promoting transformational practice (Harris, 2008); to a ‘lack of professional development availability to model effective use of new technology’ (Cowan, 2011, p1).

At the heart of these issues lies the teaching profession as the key mediating agency if society is to cope with the social change and upheaval of the knowledge age (Moreno, 2005; Schleicher, 2015). Livingstone *et al.* (2012) describe the teacher as the ‘knowledge worker’ who is pivotal to facilitating the needed change in schooling systems. The authors bemoan the fact that unlike student learning ‘so little is known about the learning process of these (teacher) knowledge workers’ (p1). Padilha (2013) advocates the need for ‘new didactics for teacher education before new didactics for students’ and the creation of 'disruptive training designs' for technology use in order for 'teachers and schools to incorporate a real culture of change' that integrates 'other epistemological and perceptual possibilities for knowledge construction' (pp233-235). Fisher *et al.* (2016) describe the phenomenon of 'inertia' where teacher education institutions 'may experience a variety of internal constraints that inhibit change' or may be 'constrained in bringing about change by their dependence on other bodies in the education system' (p83).

2.1.2 ICT in Teaching and Learning

One interpretation of all of this according to an OECD (2015) report on *Students, computers and learning: making the connection* is that 'we have not yet become good enough at the kind of pedagogies that make the most of technology' (p3) and that simply adding 21st century technologies to 20th-century teaching and learning practices will dilute the effectiveness of current practices. The literature however presents a rich stream of case studies portraying potentially promising models of teaching and learning and teacher professional learning with and through technology – what Power *et al.* (2014) describe as 'quality without quantity' (p20). McDonough and Le Baron (2010) report on early case study research suggesting 'the extensive and persistent use of such constructivist techniques as electronic portfolios, shared workspace, project-based research in teacher education [that] point to more positive attitudes and more effective subsequent use of ICT in schools' (McKinney, 1998 and Kim, Sharp and Thompson, 1998; cited in ibid., p31). An early case study from the African context was the Digital Education Enhancement Project (DEEP) in Egypt and South Africa (2001-2003). The DEEP pilot showed how a limited range of new technology[4] deployed in the context of professional development and participatory research, with supportive curriculum materials and ongoing peer-support 'can have a significant role to play in transforming the opportunities for teacher education' and 'had positive effects on areas central to UBE [Universal Basic Education] including attendance, motivation and the quality of student learning' in literacy, numeracy and science (Leach *et al.,* 2006, p96). A particular feature of the DEEP research findings was teacher reporting on affordances (opportunities and constraints) of device limitations which 'while challenging in one way – actually promoted them to adopt new classroom practices' (Leach *et al*., 2006, cited in Power *et al*., 2014, p20).

More recent studies have emphasized the potentially 'transformative' role of new technology use to support educational activities and promote 21st century skills (Haßler *et al.*, 2016, p9). In a meta-

[4] A laptop and printer/scanner (shared between a pair of teachers), a handheld 'pocket-computer' each, and a digital camera and video camera (shared between several local schools)

review of the effects of innovative science and mathematics, Savelsbergh *et al.* (2016) describe studies of ICT-rich teaching approaches inclusive of (individualized) computer-based instruction, games, feedback, interactive quizzes, computer based labs, simulations and robotics as leading to gains in more positive attitudes where 'students enjoy working with computers, students feel more safe to experiment and make mistakes, and/or students appreciate the (quick) feedback' (p162). However, the authors found that innovative strategies (computer-based, inquiry-based, context-based, collaborative learning, extra-curricular activities) produced effects in student attitudes and achievement in science and mathematics that were not significantly different between approaches. The authors propose an interpretation that suggests the type of innovative approach as having less significance than 'the quality of the content and the implementation' (p168). Loveless (2011) however relates on more recent research into the role of technologies for enhancing 'good pedagogical design' to express congruence between content and implementation (teaching strategies, learning environment, assessment and feedback, underlying learning theories) (p303). The author defends educator technology use as grounded in 'Why?', 'What?' and 'How' questions around their vision and beliefs about 'why they think their practice matters and how they can best design experiences and environments for learners' (p311).

The Horizon 2016 K-12 report (NMC-COSN, 2016) relates two major trends and uptake of ICT in education systems that would appear to challenge 'sub-optimal' (OECD, 2015, p6) use of technology in educational practice, as in: international trends towards redesigning learning spaces 'to accommodate more immersive, hands-on activities' and towards rethinking of how schools work 'in order to keep pace with the demands of the 21st century workforce and equip students with future-focused skills' (op. cit., p1). There is a growing emphasis on the use of technology to support deeper learning approaches for engaging students in 21st century skills of 'critical thinking, problem solving, collaboration and self-directed learning' (ibid., p14). It is driven by trends towards innovative learning approaches for 'project, competency- and challenge-based learning' and school structures 'that enable students to move from one learning activity to another more organically, removing the limitations of bell schedules' (ibid., p10).

Examples of technology use for deeper learning include the European Union (EU) Go-Lab project and online portal offering innovative, interactive, collaborative and context-aware tools and functionalities that provides a student-centred interface to promote contextualized and adaptable learning experiences (EU-Go-Lab, 2017). Xenofontos *et al.* (2016) report on research findings illustrating the capacity of the Go-Lab interactive learning system (ILS) to facilitate the advancement of content knowledge, while the authors report that the development of inquiry skills would require longer duration of experiences with such learning environments. From the US Dede (2014) describes the EcoMUVE (multi-user virtual environment ecosystem) middle grade curriculum initiative engaging students to assume the role of scientists, investigating research questions by exploring the project virtual environment and collecting and analyzing data from a variety of sources over time. Findings from the project research showed that while students were initially preoccupied with the technology interface of itself, with time they became 'increasingly engaged in the student-led, collaborative inquiry experiences afforded by the embedded scientific investigation' (Metcalf *et al.*, 2014, p1).

Trends related to the growing accessibility of mobile technologies in the form of smart phones, hand held digital assistants and ubiquitous laptop computer distribution point to increasing affordances for learners 'to work more continuously across home and school settings, [in] activities to be initiated outside the school, or practice on exercises to be undertaken when or where desired' (Passey, 2010, p69). Moreover, the mobile devices come equipped or ready for social media applications like Facebook, Twitter, Wikipedia, YouTube, WhatsApp, Telegram, Instagram, Snapchat 'which are part of what is known as Social Web 2.0, best characterized by the notions of social interaction, content sharing, and collective intelligence' (Alabdulkareem, 2015, p214). Educator perspectives have been raised on adapting these kinds of tools and creative media skills for engaging students 'to become the authorities on subjects through investigation, storytelling, and production' (NMC-CoSN, 2016, p18). For example, students and teachers in New Zealand and Singapore are using WhatsApp as a platform to build intercultural understanding and to foster longer term teacher collaboration towards meeting student 21st century learning needs (Asia New Zealand Foundation, 2016). Similarly, social media platforms like Twitter are being used by teachers and students in a multiplicity of ways, for example: to discover new information; to generate discussion, interest and collaboration; to connect with local and global issues; to explore, exchange and publish thoughts, ideas and perspectives; to communicate information and join professional learning networks (Shannon *et al.*, 2011; e-Learning Industry, 2016).

A more intriguing trend is the emergence of coding as a new literacy (NMC-CoSN, 2016). Schools worldwide from basic to tertiary levels are introducing and developing coding programmes in which students collaboratively design websites, develop educational games and apps, and design solutions to challenges by modeling and prototyping new products – using user-friendly tools including Raspberry PI, Scratch, and LegoNXT (Sawyer, 2012; Gardiner, 2014; Austen and Martin, 2015). The literature shows interventions like these presenting significant potential for teaching mathematics, science and language 'in ways that stimulate learners' various abilities, such as problem solving and logical thinking' (Choi *et al.*, 2013, p3), in developing 'their creativity [to] make multimedia products, and share them with their friends on social media' (Wilson & Moffat, 2010, p1), and in building their capacity 'for visualizing, remixing, tinkering, and gaining a sense of empowerment' (Koh, 2013, p1826). However, Alabdulkareem (2015) holds that while the infrastructure (social media, web 2.0) may be available, 'the comprehensive educational view is absent' and suggests that 'there is a need for training to evaluate own use of social media, to enhance the abilities to use available properties' (p213). Schleicher (cited in OECD, 2015) would concur where he considers that 'we need to get this right in order to provide educators with learning environments that support 21st-century pedagogies and provide children with the 21st-century skills they need to succeed in tomorrow's world' (p6).

Butler *et al.* (2013) suggest that given the complexities of the pedagogical integration of ICT in school systems, the need is for frameworks that can go some way towards organizing the discussion and conceptualization of what being a digital teacher in a 21st century classroom can look like. Power *et al.* (2014) concur on the need for conceptual frames that explicate clear theoretical principles for teacher learning in a knowledge age - such as principles of collaboration, knowledge construction and human agency. In this the authors advocate for new research designs beyond the Randomized Control Trialling (RCTs) beloved of governments, donors and economists 'that show learning outcomes [but] do not address practice' and where 'it [change in practice] is typically based on teacher self-reporting' (p34). In this many authors lament the dearth in studies that actually *observe* what happens in real school and classroom settings of technology integration initiatives and that *measure* aspects of practice using frameworks that can allow comparison with other approaches (ibid.; O'Sullivan, 2005; Jaipal & Figg, 2010; Agyei & Voogt, 2011; Butler *et al*., 2013; Terpstra, 2015). In this regard, Haßler *et al.* (2016) argue that the implementation of technology in the classroom should not be treated as a 'one-off process', and advocate the conduct of more pragmatic and iterative approaches for 'developing robust designs that can be sustainably implemented in classrooms' (p4).

A critical aspect of this research then will be to explore frameworks aimed at understanding the complexity of teacher professional development for ICT integration in relation to: the schooling context as a professional learning space whose affordances can both influence and constrict opportunities for change; teacher professional community development of practices for ICT use relevant to their school and classroom contexts; student 21st century learning opportunities related to the affordances of new technologies and pedagogies for promoting deeper learning; and tracking teacher perceptions, observations and measures of what works, in which context, how and why as they engage in ICT use in the different phases of their professional learning in the SIPSE intervention.

2.1.3 The ICT in STEM Agenda

The African Union (AU) (2016) describes an African continent in the 21st century as 'poised to shape its own destiny' (p9) with assets that go beyond its bountiful resources many of which are yet to be tapped (such as minerals and oil and the boundless possibilities for clean energy). The AU has developed a *Continental Education Strategy for Africa 2016 – 2025* (CESA 2016-2025) to address the first ten years of its *Agenda 2063* (AU, 2015) global strategy to ensure positive socioeconomic transformation within the next 50 years. As the youngest continent in the world[5] the AU argues that Africa's prosperity can be achieved 'only if the continent invests in the education and training of its youth' (op. cit. p10). Akyeampong (2016) describes the 21st century as a century of hope for Africa citing IMF projections for significant growth 'nearly at the same rate as Asia' and describing a continental 'enthusiasm for technology' currently manifested in some '600 million mobile-phone users, for example, more than America or Europe' (p1). Whether or not African youth can avail of the momentum that current rates of economic and technological growth present will depend on the kind of 'modern knowledge and skills' they experience in their education - particularly 'the kind of Mathematics and Science skills' that meet the demands of the modern workplace and the regional aspirations for 'the transformative shift of Africa' (ibid). In this a report by the African Capacity Building Foundation (ACBF, 2016, cited in SciDev.Net Blog, 2016) highlights critical skills gaps for the realization of Agenda 2063 with current continental shortfalls of some five million scientists and engineers while more than eighty percent of students are enrolling in social sciences and humanities courses. The ACBF executive secretary Emmanuel Nnadozie, declared that 'real African transformation will not happen unless countries give priority to STEM' where an 'emphasis on STEM could resolve unemployment issues in Africa' (ibid.).

It is a call that is echoed in education systems globally where debates rage on student requirements in STEM to meet the demands of the 21st century workplace (Williams, 2011; Ostler, 2012; De Angelis, 2015). Ostler (2012) holds STEM education as markedly under-conceptualized among 'politician, educational reformist and even educators in STEM disciplines' (p28) in relation to what it is and how it should be facilitated. The confusion lies in the spectrum of philosophies and definitions in offerings of STEM from an additional emphasis on 'the traditional topics in

[5] Africa's population is growing faster than Asia's and is set to double from current level of one billion in little more than a generation (The Economist 2013). By 2035 the continent's labour force will be larger than that of any nation, including China or India (McKinsey 2012).

mathematics and science' to STEM conceptualization 'as a non-exclusive meta-discipline' to provide meaning for each discrete subject through 'contextualizing it with others' (ibid, p29).

In the literature, the traditional STEM acronym relates to the subjects of Science, Technology, Engineering and Mathematics. However, in the SIPSE intervention the STEM acronym refers to Science, Technology, English (not Engineering) and Mathematics subjects. Furthermore, in the SIPSE acronym Technology refers to both the subject and the use of technology as a tool to enhance subject teaching and learning. In this study the focus is the latter aspect of ICT use to enhance Science, English and Mathematics classroom practices – while the wider SIPSE programme centres on ICT use in all STEM subjects.

Ostler (2012) cautions on new scenarios for giving traditional STEM pedagogy and curricula a new name that fails to address 'the underlying problems that students have in learning even basic mathematics and science' and as such continue to produce 'disappointing results' (p29). In this Akyeampong (2016) relates on reports from the *Trends in International Mathematics and Science Study* (TIMSS) (Reddy *et al.*, 2015, cited in ibid.) and UNESCO's *Global Monitoring Report*s (GMR) (UNESCO 2012) establishing African student performance in mathematics and science as having been 'persistently low compared to international/ national benchmarks' (op. cit. p5). The striking observation according to Akyeampong is the level of student performance that undermines aspirations for transformative shift in Africa's development - where students perform well in levels of 'factual knowledge' (science) and 'facts and procedures' (mathematics) instead of levels of 'conceptual understanding, reasoning and analysis' (science) and 'using concepts for solving routine and complex problems' (mathematics) (ibid.).

De Angelis (2015) argues the requirements for students' adeptness in skills that go beyond STEM factual knowledge such as 'critical thinking, problem solving, persistence, collaboration, and curiosity' (Enterra Insights Blog). Bailey and Kaufman (WEF, 2015) in a study they developed for the *World Education Forum - Industry Agenda* propose 'a new vision for education' that unlocks 'the potential of technology' to foster such skills within a 21st century frame integrating three dimensions of life-long learning, namely: 'foundational literacies, competencies and character qualities' (p3) (Table II). In their study of *Skills for Employability in Africa and Asia* Burnett and Jayaram (2012) categorized skills at secondary level in three domains of 'cognitive' (numeracy and literacy), 'non-cognitive' (behavioural and attitudinal encompassing 21st century soft skills and entrepreneurial skills) and 'technical' (specific to vocational and craft competencies) as having importance (pii) (Table II). In a parallel study of *Innovative Models for Skills Development in Africa* *and Asia* Birmingham and Engmann (2012) explain the focus on secondary education as related to a new prioritization and rising demand for this level as the point from which most young people currently enter the labour force in Lower and Middle Income Countries (LMICs)[6]. An unexpected finding from the studies were employers' concerns for graduates with *non-cognitive* as much as cognitive and technical skills in both formal and informal economies – where the latter provides employment for as many as nine out of ten workers in developing countries. However, the studies highlight the significant lack of non-cognitive 'life skills' in traditional secondary curricula and where included 'it is not in a way that is helpful to teachers in understanding what employers are looking for' (op.cit.).

Williams (2011) relates a public-private dissonance in these educational debates in his contention of 'a non-educational rationale' as driving STEM and 21st century skills movements (p31). The author assesses vocational and socio-economic goals and high profile partnerships (companies, foundations, non-profit organizations and science and engineering societies) as pushing the agenda of STEM activities 'to better equip a workforce' rather than 'the quality of learner outcomes' (ibid). Conversely, Akyeampong (2016) points to a crucial role in relevant mathematics and science education (MSE) in Africa to address the phenomenon of the 'silently excluded' crisis in schooling where 'many children don't learn much even if they stay on to complete [secondary] education' (p3). There is a new urgency for education systems to equip learners with STEM and 21st century higher level capabilities for promoting 'relevant transferable skills for *all* children' [emphasis added] that are adequate to helping them 'adapt to different work environments and contribute to sustainable development' (ibid). Voogt and Roblin (2012) centre the challenges for education systems in a knowledge age as being 'asked to prepare young people for a job that does not exist' – a job which is no longer related to 'the exchange of information only' but to 'a *particular understanding* of information' [emphasis stated] (p 300). In this Ostler (2012) justifies the emphasis in STEM education to endow young people with relevant skills for the future of work, as in: 'scientific inquiry methods [and] effective heuristics for knowing, testing, and verifying information in order to have the tools to understand how information is interactive, interdependent, and adaptable' (p30); and 'skills in interpreting, analysing and manipulating data to harness opportunities for sustainable development' (op. cit., p7).

Voogt and Roblin (2010, 2012) relate the need for drastic changes in national curricula in order to comply with 21st century skills development. The authors maintain that policy-makers do not seem

[6] Africa is an exception where secondary education is growing rapidly but still enrolls less than 40% of students of secondary age.

to link findings from regional and international learner achievement studies to the 'need to restructure curricula in order to realize 21st century competences' (ibid., p301). They contend that positioning 21st century skills within the existing curriculum 'is perhaps one of the most complex and controversial issues of its implementation' (op. cit., pi). Williams (2011) laments the integration of technology in the 'unchallengeable high ground' (p27) of the school curriculum structure as serving the need for reform in MSE 'rather than the goals of technology' as a 'significant component' in the reform agenda (p29). The complexity of the debates is manifested in the proliferation of frameworks in the 21st century skills landscape where references to skills can be found under 'various terminologies' across initiatives and curricula (Voogt & Roblin, 2012, p31). The commonality among frameworks is the situating of ICT as a core competency which Voogt and Roblin (ibid) concur should not be regarded as simply a 'new competency' but rather should be 'associated to a whole new set of competencies about how to effectively use, manage, evaluate and produce information across different types of media' (p308).

Table II maps 21st century skills frameworks discussed in this section that positions common features of competence alignment in terms of foundational, transferrable and technical skills. The table includes the addition of competence sets for primary and secondary tiers of educational delivery that form part of the Kenya Institute of Curriculum Development (KICD) new proposal for curriculum reform in Kenya.

Table II - Frameworks for 21st Century Competencies & Skills (Sources: Bailey & Kaufman, 2015; Burnett & Jayaram, 2012; Juang, 2016)

World Economic Forum: Industry Agenda - *Life Long Learning*	***Innovative Secondary Education for Skills Enhancement***	***Kenya New Curriculum Proposal (2016)*** *Skills for Learners – in friendly, inclusive and affordable school environments*
16 Skills for 21St Century	**Skills for Employability in Africa and Asia**	**1st Tier Skills** Pre-Primary and Lower Primary (5 years)
Foundational Skills *Student application of core skills to everyday tasks* • Literacy • Numeracy • Scientific Literacy • ICT literacy • Financial Literacy • Cultural and Civic Literacy •	**Foundational Skills** • Basic cognitive skills to think, study and learn • Numeracy and Literacy	**Foundational Skills** • Numeracy and Literacy **Specific and technical skills** • Digital Skills **Socio-cultural Skills** • Life Skills
		2nd Tier Skills Middle primary and lower secondary (6 years)
Competencies *How student approach complex challenges* • Critical thinking/ problem solving • Creativity • Communication • Collaboration	**Cognitive skills** Openness to learning **Non-cognitive skills** • Communication: oral and written • Work habits: punctuality, application… • Teamwork • Entrepreneurialism	**Cognitive Skills** • General knowledge **Specific & Technical Skills** • Practical skills • Technology Skills **Socio-cultural skills** Values

***World Economic Forum: Industry Agenda** - Life Long Learning*	***Innovative Secondary Education for Skills Enhancement***	***Kenya New Curriculum Proposal (2016)*** *Skills for Learners – in friendly, inclusive and affordable school environments*
	• Personal integrity • Leadership	• Self-reliance • Integrity • Patriotism
		3rd Tier Skills Upper secondary (3 years)
Character Qualities *How students approach their changing environment* • Curiosity • Initiative • Persistence/ Grit • Adaptability • Leadership • Social and Cultural Awareness	**21st Century Skills** Skills for work in today's global, 21st century economy • Core subjects • Life and career skills • Learning and innovation skills **Specific and technical skills** • Language (mainly English) • Basic business skills • ICT skills • Specific to context – with practical and theoretical perspectives **Character Qualities** Skills collected in packages of *"life skills"* considered important	**21st Century Skills – 4Cs** • Communication • Collaboration • Critical thinking • Creativity **Specific and technical Skills** • Computer and Digital literacy • English Language/ Literature • Home science, Art &craft, Agriculture and Woodwork **Character qualities** • Accountability, Integrity, Responsibility, Peace, Commitment to work, Negotiation, Acceptance and Environmental Preservation
Source: WEF, Bailey and Kaufman (2015)	Source: Results for Development, Burnett and Jayaram (2012)	Sources: Juang, (2016)

The KICD new curriculum proposal is based on a needs assessment study (Juang, 2016) conducted among national stakeholders. The proposal seeks to address the 'widely criticized [current curriculum] for being expansive, heavily loaded in terms of content and too examinations oriented, which when combined put pressure on learners' (Wanzala, Daily Nation, March 31, 2016). Central to the proposal at secondary level are '4C' 21st century skills sets (communication, collaboration, critical thinking and creativity), digital and language literacies identified by Kenyan teachers and principals as 'skills you should be able [to have] to be a good decision maker… and [to be] creative and analyse situations in order to make the right choice where you're faced with difficulties' (ibid., p18). Whether the proposal will be realized is another challenge given Voogt and Roblin's (2012) observation that 'it is worrying that the education sector, let alone schools and teachers, do not seem to be actively involved in the 21st century initiatives and in the overall debate about these competences' (p305).

While there are patterns of horizontal consistency across 21st century skills frameworks in relation to curriculum intentions for reform and transform as presented in the Kenya proposal, there remain critical caveats in vertical consistency related to coherence between intentions, implementation and assessment of outcomes (ibid., p302). Akyeampong (2016) would concur on the 'gap between desired competencies that [STEM] should foster, and what happens in the actual process of teaching and learning in these subjects' (p8). The author suggests that the answer lies in much more than ‘curriculum statements’ calling for reform and taking a closer look in ‘how we train our teachers’ (p2).

In this study the STEM focus is teaching and learning of Science, English and Mathematics that is underpinned by Technology subject teaching and the use of ICT to enhance innovative practice. The issues of building teacher capacity to use technology as a mediating tool for improving the practice, quality and relevance of STEM education and 21st century skills are presented in the following section.

2.2 Re-conceptualizing Teacher Education and ICT Use for a Knowledge Age

A quality education is dependent on the development of quality teachers (Haddad, 2007) where the received wisdom suggests that the quality of an education system cannot exceed the quality of its teachers (Albion & Jameson-Proctor, 2009). Teacher education therefore plays a crucial role in updating teaching and learning practices and learning environments to meet 21st century high levels skills and creativity needs and demands (Teräs *et al.,* 2010).

The challenge of quality education provision is momentous in the global context of ever more complex demands on education systems in the knowledge age (Spring 2008; Leach 2008). The challenge is in almost all respects greatest in LMICs and in particular in the rapidly expanding secondary sub-sector level of these countries – where qualified teachers are becoming ‘a precious commodity’ (Moreno, 2005, p286) and where attrition rates are the highest in the teaching profession particularly among high demand subjects of Mathematics, Science, Technology and Language (especially English) (Ottevanger *et al.*, 2007; USAID, 2008). In Kenya the dilemmas of quality provision are underlined in government strategies for the introduction of free primary education (FPE) (started in 2003) and free secondary education (FSE) (started in 2008). The strategies have resulted in major breakthroughs in expanding access and equity amidst growing concerns on the capacity of the education system to provide inclusive and quality education (Gakuu *et al*., 2011). Here the National Union of Teachers (KNUT) estimates shortfalls of up to one hundred thousand teachers at primary and secondary levels ‘representing the greatest challenge in the provision of access to quality education in the country’ (Daily Nation, 2014).

Akyeampong (2002; 2016) considers teacher quality and the ‘role teacher education should play in its improvement’ as increasingly becoming ‘an important subject in education development on the [African] continent’ (op. cit., p11). By the same token the Education for All (EFA) Global Monitoring Report Team (2015) observe that attention paid to ‘*teachers* and *teaching’* has not been as strong as the 'increased interest in student learning' in the quality education debates (p4). The Asia Society (2015) attributes the predicament of modernizing teaching in the knowledge age as inherent in the model of teaching as a stand-alone activity (particularly in the west) representing perhaps the only 'solo profession left into today's economy' (p16).

It is in this context that many experts in the fields of education and ICT consider that the use of new forms of technology can be exploited to strengthen and enhance the quality of education in general and teacher education and innovation in particular (Leach, 2008; Cowan, 2011; Gacicio, 2013; Schleicher, 2015; Akyeampong, 2016). The potential impact of ICT in education is the vision that it enables learning 'anytime, anywhere and anyhow' - where knowledge is not constrained by geographic proximity and where there are almost limitless opportunities for sharing, archiving, retrieving, using, building and creating knowledge. Indeed, trends for ICT investment in education systems have been gathering momentum globally in recent decades to support national reform and transformation agendas in relation to access and quality, curriculum and assessment, pedagogy, technical and vocational training, teacher development and alternative models of delivery and provision (Evoh, 2007; Leach, 2008; Ng, Miao & Lee, 2008; Redecker & Johannessen, 2013). In Kenya the government has been implementing the *National ICT strategy for Education and Training* developed in 2006 with a focus advocacy on the use of 'innovative practices in the implementation of ICT in the curriculum' (Murithi *et al.*, 2013, p197).

There is, however, much hype in the literature on the potential of ICTs to both assist education systems achieve their mission for educational reform and to transform and innovate educational practice. As discussed in the previous section, the positive impact of technology integration in education and on student achievement has not been proven despite thousands of impact studies (InfoDev, 2015). Andreas Schleicher, OECD Director for Education and Skills, contends that school systems need to invest more strategically in technology integration for more effective pedagogies that can build student 21st century skills (OECD Blog, 2015b). Moreover, the investment needs to 'ensure that teachers are at the forefront of designing and implementing this change' (ibid.). In contrast McDonough and Le Baron (2010) argue that unless technology disrupts 'grammar of schooling' assumptions of fixed knowledge organization and rigid curricular design as discussed in the previous section, 'it will fail to produce meaningful improvement' (p17).

The issues of technology disruption as a pre-requisite for school transformation point to multi-faceted dimensions for ICT integration in school systems in the knowledge age. In Kenya Gakuu *et al*. (2011) advocate the necessity to equip educators and administrators with expertise for supporting whole school ICT development in order to support teachers' pedagogical integration of ICT in classroom practice. Hammond (2013) argues that the need is to build a better understanding of the interplay between the individual agency of the teacher and their school contexts in change processes. Yet Akyeampong (2002) points to a paucity of teacher education models and research that 'reflect African concerns' for 'deepening teacher understanding of local needs' and 'changing the way in which teachers have traditionally viewed their roles and responsibilities in the classroom' (p12). O'Sullivan (2005) would concur highlighting a dearth of studies in the African literature that are grounded in the classroom 'and the processes of teaching and learning taking place there' (p305). She attributes the challenges as related to a status of classroom-based research methods which do not feature highly in quality reform agendas in the African context. The issues appear centred on quality distortions in developing countries dependent on 'international donors for financing educational reform' - where indicators are more often focused on quality as inputs (teachers, PTR, textbooks, electricity) and narrow outputs (examination statistics) in preference to processes (teaching and learning in the classrooms) (ibid.; Matt, 2014)

In sum, there would appear to be a gap in the general and African literature on effective teacher development for ICT use in the locale of classroom teaching and learning processes. On the basis that key objectives of this inquiry were to track teacher perceptions and applications of ICT in practice, it was apposite to develop a more nuanced understanding of environmental affordances enabling or inhibiting teacher technology use in classroom teaching and learning processes. Accordingly, the following section identifies three lenses for conducting a broader and deeper examination of teacher education models for ICT use in general and the SIPSE model for ICT use in STEM teaching and learning in particular.

2.3 Three Lenses for Examining Teacher Development for ICT Use

2.3.1 The UNESCO ICT Competency Framework for Teachers Lens

In spite of the exponential growth of computers in education systems, the use of ICT by teachers has been criticized as being infrequent and focused on information transmission rather than the facilitation of student knowledge construction (Chai *et al.*, 2011; McDonough & Le Baron, 2010). Abrami (2001 cited in Mueller et al., 2008) attributes ICT non-use for deeper learning as due to a lack of teacher competency and experience in the 'craft' of computer integration (p1524). Mueller *et al.* (2008) point to the phenomenon of continual changes in technology placing teachers in the position of being 'perpetual novices' in its integration (pp1524-1525). The authors refer to teachers stuck in 'recursive cycles' of training in less sophisticated levels of technology use that enable teachers to do the same things they always do – ‘only faster’ (ibid.). Farrell and Isaacs (2007) in their ground-breaking survey on *ICT in Education in Africa* report on ICT in teacher education initiatives as fragmented involving ‘one-off, topic-led, short-term training programmes that aim to develop specific skills of teachers, but which do not necessarily comply with professional standards of competency development’ (p20). The challenge lies in the lack of clarity in the literature and educational practice as to what are the dimensions of knowledge age technology competencies teachers need to develop and what they actually would look like in their work practice (Mandinach, 2005; Kirschner *et al.,* 2008).

An ICT teacher competency describes what a teacher should know and be able to do with technology in professional practice. An ICT teacher standard is a combination of attributes describing a teacher’s professional performance involving the use of ICT (Scheffer & Logan, 1999). The ‘knowing’ and ‘doing’ and ‘performance’ components are critical in recognizing competence as an attribute that is essentially realized in action – as in developed in ‘real rather than simulated professional development contexts’ (Moreno, 2005, p17). There have been various frameworks proposed by experts to develop teacher competency in general and teacher ICT competencies in particular (Collis & Moonen 2001; Kirschner & Davis 2003; Unwin 2004; Olakulehin, 2007). From a general teacher development perspective, Passey (2014) proposes a framework integrating three sometimes overlapping stages in what he describes as a ‘teacher professional development (TPD) journey’. Here a teacher develops competences in different teaching modes (approaches) over time while working with others (learners, teachers, staff, parents and outside agencies) in classroom and school environments, namely: knowledge transfer (KT), knowledge sharing (KS) and knowledge community (KC) modes. A critical feature of the framework is the concept of teacher ‘signature pedagogies’ or ‘fundamental ways in which future practitioners are educated for their new professions’ (Shulman 2005, cited in ibid., p5) and whether TPD frameworks can challenge and change teacher fundamental approaches in their specialist areas (such as STEM subject teaching) (Table III).

From a more bespoke teacher development for ICT use perspective, UNESCO (2008, 2011) launched, tested and developed an ICT-Competency Framework for Teachers (ICT-CFT) as an attempt to develop a continuum approach for teacher development in ICT use – from pre-service to in-service. The competencies are based on the premise that educational change through ICT should also be perceived as moving through three dimensions - progressing from ‘technology literacy’ to ‘knowledge deepening’ and ‘knowledge creation’ purposes. Each dimension develops increasing teacher capacity and empowerment in ICT utilization as a tool to enhance the quality of learning (Adam *et al.*, 2011) (Table III).

A common feature of both the Passey and UNESCO frameworks is the focus on phased approaches for change and development where the 'acquisition of [professional] learning is concerned with student benefit – with widening and deepening opportunity and potential' (op. cit. p5). Nevertheless, Voogt and Roblin (2010) in an analysis of characteristics of new and emerging TPD frameworks such as these critique their tendencies to place emphasis on 'teachers' pedagogical and technological knowledge' (p32). The authors assert that development of teacher capacities 'to diagnose students' prior knowledge and learning styles with regard to 21st century skills' discussed in the previous sections 'do not receive much attention' (ibid).

A more consensual view from the literature emphasizes the need to recognize the challenges that new or reconceptualised TPD frameworks pose for addressing 21st century learning applications in practice (Voogt & Roblin, 2012; Butler *et al.*, 2013). More emphatically there is a need to give teachers the opportunity to develop ICT and 21st century skills themselves in a way that 'transforms how they are educated [in their specialist fields] and at the same time experience how these skills can be brought into classrooms' (Akyeampong, 2016, p7). In sum, it is a transformative view of teacher professionalism to develop teachers' own 21st century creative and innovative capacities so they can in turn promote their students' development of their critical and transformative capacities (Sachs, 2007). Nonetheless Voogt and Roblin (2012) note that this type of teacher support 'receives little attention in different frameworks' (p32).

Table III - Phased TPD Approaches towards 21st Century Learning (Sources: Passey, 2014; UNESCO, 2008, 2011; Voogt & Roblin, 2012)

Teacher Professional Learning Journey Modes	***Teacher ICT Competencies & Approaches***	***Student 21st Century Learning***
Knowledge Transfer Mode • Sets **clear learning parameters** • Focus on simple forms of formative assessment • Learning is something that students receive and gain • Wants learner attention and focus through quite strict control • Wants learners to get things 'right'	**Technology literacy approach** • Improving basic literacy skills through the integration of various technologies, tools and e-content as part of whole class, group and individual activities. • Pedagogical approaches focus on **standard teacher led didactic** approaches	**Cognitive Skills** • Critical thinking • Based on routine problems **Technological skills** • Media literacy (information, technology and ICT)
Knowledge Sharing Mode • More focused **on differentiated learning** and group work	**Knowledge deepening approach** • Emphasizing skills in use of more sophisticated technology to improve **depth of**	**Cognitive Skills** • Critical and creative thinking • Based on routine and complex real world problems

Teacher Professional Learning Journey Modes	*Teacher ICT Competencies & Approaches*	*Student 21st Century Learning*
• Still defines parameters of learning • Gives learners more space to share in learning activities • Use more sophisticated forms of formative assessment	**understanding** over coverage of content • Assessment emphasizes the application of understanding to real world problems. • Class periods & classroom structure are more dynamic.	**Sociocultural Skills** • communication, collaboration • conflict resolution beyond their cultural contexts **Technological skills** • Make responsible and intelligent use of ICT as an enabler of productive work
Knowledge Communities • Teachers as master learners **continually learning about student individual needs** and interests • Gives learners responsibility to direct their learning • Considers new arrangements of learning spaces, times and resources available in the school • Deepens a use of powerful assessment techniques	**Knowledge creation approach** • Goes beyond a focus on school subjects to explicitly include 21st century skills. • Developing sophisticated professional skills to support students who are **creating knowledge products** and planning and managing their own learning goals and activities • Schools are transformed into learning organizations	**Metacognitive Skills** • Develop student' engagement in the self-regulation required for learning-to learn • Develop dispositions for life-long learning **Productivity Skills** • Real-world expectations and outcomes • Learn how to develop productive and efficient work processes • Prepare students to become twenty first century 'knowledge workers'
Source: Passey (2014)	Source: UNESCO (2008, 2011)	Source: Voogt and Roblin(2012)

The UNESCO ICT-CFT framework promotes its teacher development model for ICT integration across 'six key aspects of a learning system' (Butler *et al.*, 2013, p2) related to *Understanding ICT in Education (Policy), Curriculum and Assessment, Pedagogy, ICT, Organization and Administration* and *Teacher Professional Learning.* The interplay between the learning and phased approach components of *technology literacy, knowledge deepening and knowledge creation* is mapped in Table IV. Each component in the table represents a modular space for building teachers' ICT competencies (UNESCO, 2011) while 'for change to occur, there must be movement across and between the components' (op cit., p3).

Table IV - UNESCO ICT Competency Framework for Teachers (Source: UNESCO, 2011)

	TECHNOLOGY LITERACY	KNOWLEDGE DEEPENING	KNOWLEDGE CREATION
UNDERSTANDING ICT IN EDUCATION	Policy awareness	Policy understanding	Policy innovation
CURRICULUM AND ASSESSMENT	Basic knowledge	Knowledge application	Knowledge society skills
PEDAGOGY	Integrate technology	Complex problem solving	Self management
ICT	Basic tools	Complex tools	Pervasive tools
ORGANISATION AND ADMINISTRATION	Standard classroom	Collaborative groups	Learning organizations
TEACHER PROFESSIONAL LEARNING	Digital literacy	Manage and guide	Teacher as model learner

Since its launch several countries and programmes have adopted the ICT-CFT to guide the design and implementation of their TPD programmes for ICT use. Guyana's national strategy for ICT integration in teacher professional development (Commonwealth of Learning, 2012a) and Egypt's Professional Development Roadmap (Egyptian Education Imitative, 2008) were informed by the learning system perspectives of the ICT-CFT. The online teacher development programmes of the OER4Schools Professional Learning Resource (University of Cambridge, Faculty of Education, 2015) and the Commonwealth Certificate for Teacher's ICT Integration (Commonwealth of Learning, 2012b) drew on the ICT-CFT to inform different levels of their e-learning course design.

Some authors point to the limitations of such competency frameworks. Sachs (2008) cautions on dual dimensions of teacher standards which on the one hand 'seek to build and hone teacher creativity and development at the local and individual level to help teachers understand their practice and improve it'; but on the other hand can turn into extreme forms of standardization 'regulating, dictating and standardising teacher practice, removing the ability of teachers to be creative, innovative and use their professional judgement' (p196). In the same way Coolahan (2010) tracks the concept of 'competence' as shifting from a positivist perspective associated with a narrow audit checklist culture to a more liberal understanding of competence achievement as manifested appropriately in the attitudes, beliefs and personal culture of the person who achieves and exercises the competence in question. Miao (2010) advocates the need before action to understand the relation of frameworks like the ICT-CFT to national educational policies, ICT-readiness, teacher development programme design, and teachers' professional and cultural environments.

In the SIPSE project the UNESCO ICT-CFT was contextualized in national stakeholder workshops for alignment with national educational objectives. The contextualization was developed through a 5 staged process - namely: 1) needs assessment of the ICT teacher development context; 2) contextualization and prioritization of the ICT-CFT competencies for Kenyan teachers; 3) curriculum mapping of the SIPSE course based on the identified ICT-CFT priorities; 4) development of two module sets at technology literacy (TL) and knowledge deepening (KD) levels; and 5) assessment and evaluation of the modules in the SIPSE pilot intervention (Figure 2.1).

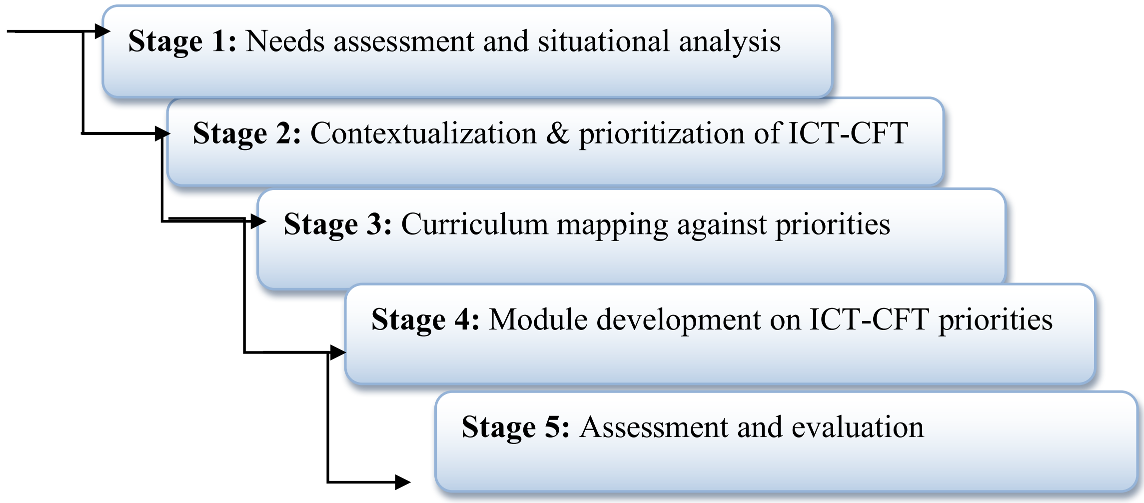


Figure 2.1 - 5 Stages of ICT-CFT Contextualization

A set of five modules and tools designed on the basis of two levels (TL and KD) of prioritized and contextualized competencies were trialled and validated in the SIPSE pilot. See Table V for an overview of the modules and Appendix 1.1 for a more detailed description of each module objectives and content. The SIPSE pilot was implemented in a blended learning format (workshops and online platform) carried out in 2014 and 2015.[7]

Table V - SIPSE ICT-CFT Modules and Content

Module	Content	ICT-CFT Level
Module 1 – ICT & Didactic Teaching	focus on • didactic teaching with ICT to support student acquisition of STEM concepts • teacher design of practice and drill activities to try-out in STEM lessons • introduction presentation, spreadsheet and word productivity tools	Technology Literacy
Module 2 – ICT & STEM Curriculum Standards	focus on • teacher search, retrieve and evaluation of STEM open education resources and software (OERs & OESs) aligned to curriculum objectives and student differentiated needs and learning styles • teacher use of ICT to support interactive active teaching and learning techniques and engagement of students with ICT • teacher design, development and adaptation of presentation, OER and OES resources in STEM activities	Technology Literacy
Module 3 – ICT in the Classroom & the Computer Lab	focus on • use of simulation tool to support interactive techniques for student engagement in discussion, higher order thinking and group work around STEM concepts • teacher design and development of simulation resources for plenary, individual and group work activities in classroom and computer lab settings	Technology Literacy

[7] Each cycle was carried out over four months: Cycle 1 from February to May 2014; Cycle 2 from September to October 2014; and February to March 2015

Module	Content	ICT-CFT Level
	• special unit on national policies & their impact on education • introducing toolkit for school review and planning for ICT integration	
Module 4 – ICT and Problem-based learning	focus on • teacher design of routine and complex-real world problem activities that serve as a basis for student acquisition and application of STEM concepts • use of brainstorming and group work organizational strategies for engaging student in problem solving processes • teacher design and integration of concept and mind mapping OES tools to support social interaction by student on problem solving tasks	Knowledge Deepening
Module 5 – ICT and Project-Based Learning	focus on • teacher design of STEM projects with cooperative learning opportunities, webquest OER and OES tools to engage students in structured STEM inquiries • guidelines on setting up project and cooperative learning opportunities in the classroom • teacher design and development of webquest resources and assessment rubrics	Knowledge Deepening

In this study the UNESCO ICT-CFT lens provides the first layer of the research conceptual framework as a guide to the SIPSE module design and as a lens for examining its professional learning intervention for ICT integration. The focus is to appraise whether teacher perception and practice changed over time as they went through the two cycles of the ICT-CFT professional development journey, as in: in the first cycle using technology to enhance conventional didactic practices and signature pedagogies in STEM teaching (technology literacy to support knowledge transfer modes); and in the second cycle experimenting with ICT to support deeper problem- and project-based pedagogical shifts in STEM teaching and learning (use of technology to promote knowledge deepening and sharing modes).

2.3.2 The Technology Pedagogy and Content Knowledge Lens

The effective integration of ICT use in the design of frameworks for teacher education programmes has faced two critical challenges. The first challenge relates to the historical focus in teacher education on developing teacher content knowledge and pedagogical knowledge in separate coursework, one in isolation of the other, with an emphasis on general pedagogical classroom practices independent of subject matter (Jimoyiannis, 2010). These issues have been resolved in recent decades with the re-design of teacher education programmes in alignment with Shulman's (1986) research and advocacy for developing teachers' pedagogical and content knowledge (PCK) capacity – that 'special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding' (p8).

The second challenge has centred on the insufficiency of teacher ICT competency and positive self-efficacy attitudes to solve what Koehler and Mishra (2008, cited in Jamieson-Proctor *et al.*, 2010) describe as the 'wicked problem' of teachers teaching with technology. The authors explain the problem in terms of finding the 'right combination of technologies, teaching goals and instructional approach' (p2). Expanding on Shulman's studies on the importance of teachers' PCK, Mishra and Koehler (2006) advocated the introduction of technology, pedagogy and content knowledge (TPACK) as a theoretical framework that teachers need to develop in order to integrate technology effectively for 21st century learning environments (Figure 2.2).

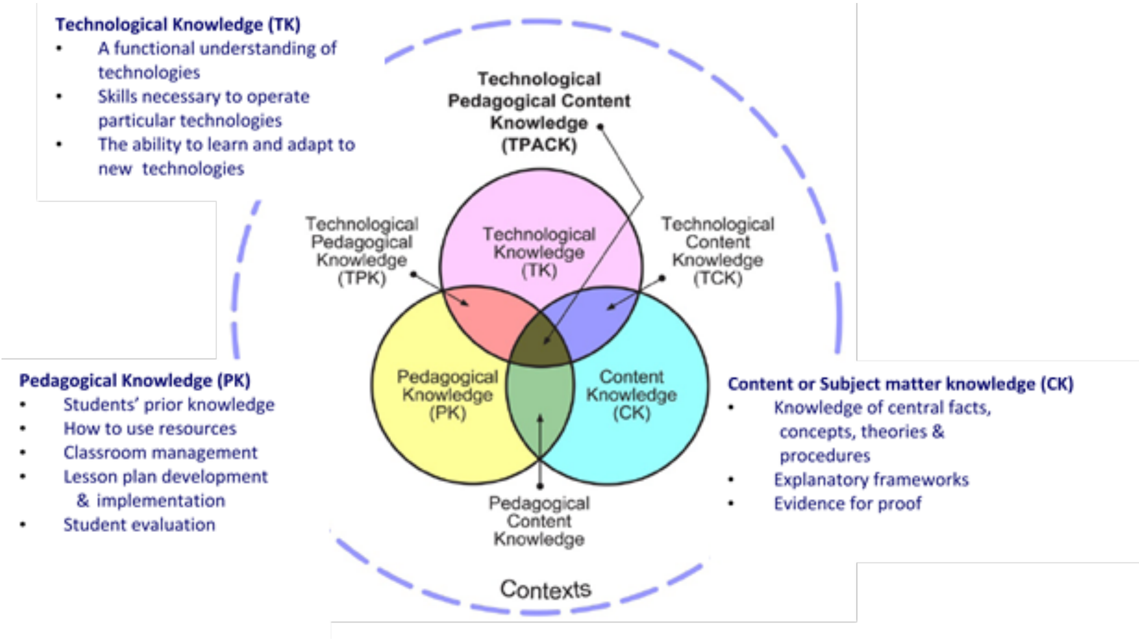


Figure 2.2 - Technology, Pedagogy and Content Knowledge (Source: Mishra & Koehler, 2006)

The framework expands understanding of the model of technology integration integral to the UNESCO ICT-CFT framework. It presents a synthesis of what teachers need to know in order to use technology to promote meaningful learning at each competency development level - from pedagogical knowledge (PK) on how to plan instruction, deliver lessons, manage students, to content knowledge (CK) about subject matter concepts, to technology knowledge on new and emerging tools (TK). The framework builds understanding on how the constructs can interact with one another to produce a whole new set of knowledge constructs, namely: constructs of PCK (how to teach content), TCK (how technology can support and change content), TPK (how technology can support and transform pedagogical strategies), and TPACK (how the teacher can holistically integrate technology into pedagogy to support content knowledge construction) for effective classroom practice and teaching and learning transformation (Jaipal & Figg, 2010; Figg & Jaipal, 2012; Tai 2013).

Passey (2014), however, reveals potential tensions inherent in the 'wicked problem' of technology integration where new methods and tools can be perceived by teachers as causing 'harm' to old approaches and 'signature pedagogies' discussed earlier in this section (p5). Muellar *et al.* (2008), however, argue an 'inverse relationship' between computer integration and beliefs where a teacher's pedagogical philosophy can be altered following technology integration interventions (p1525). Koh *et al.* (2015b), on the other hand, describe the teacher 'belief mode of thinking' that is situated in 'instructional goals pre-specified in curriculum or textbooks' as creating critical 'cognitive dissonance' conflicts when teachers attempt to change their pedagogical practices (p3). McDonough and Le Baron (2009) argue that if technology fails to 'disrupt the comfortable assumptions of traditional practice', it will fail to produce meaningful improvement and transformative practice (p17).

Speaking from an African perspective Akyeampong (2002) elaborates on the challenges of 'teacher and student roles [that] are clearly defined' within a schooling examination culture that has given 'life and sustenance to pedagogical practices founded on behaviourism' where 'student understanding of *doing schoolwork* [is of] *receiving* the teachers' knowledge' (emphasis stated) (p13). Yet like others in the general literature (Butler *et al.,* 2013; Koh, *et al.*, 2015b), Akyeampong (2016) notes that teachers and teacher educators are aware of constructive approaches centred on developing student 21st century competences 'to demonstrate conceptual understanding and effective use of this understanding' (p8). He relates teacher educator viewpoints that are sceptical about the 'fit' of education systems to achieve student 21st century learning purposes and 'teachers' ability to promote these desired competences' (p8). Hannay *et al.* (2013) see that the need is for 'fostering collective, constructive and conversational learning practices among teachers' about 'beliefs, practices, realities and change' (p66) to enable them to 'challenge current practices, explore their own tacit knowledge, develop collective explicit knowledge, innovate together, and move ideas to school and classroom practices' (p75). Similarly, Cowan (2015) speaks of teacher co-construction of new pedagogical knowledge through effective conversation that brings their pre-existing experiential knowledge to the surface. Hammond (2013) proposes the exploration of such teacher perceptual affordances for ICT use in school contexts as offering a more nuanced potential for change than the prevailing focus on teacher 'take-up of ICT *per se*' (p6). Passey (2014) asks what outcomes are achieved over time in professional development interventions to change the status quo of beliefs and practices – where 'monitoring sustained professional development change is not commonly undertaken' (p5). The author proposes systemic perspectives involving 'a pathways approach' (learning, technical, political and cultural pathways) as critical parameters to support teachers in their exploration of new technology affordances for improving and innovating practice (Passey, 2010, p5).

The TPACK lens can assist educators, teachers and researchers to assess and understand the many forms of teachers' professional knowledge and perceptions as they appear (Chai et al., 2013). It can assist in identifying emerging teachers' knowledge and belief systems that have been historically difficult to discern and to shift (Hofer *et al*., 2011). Yet a key question raised in the literature centres on how teacher proficiency in applying new TPACK constructs can be understood, developed and measured in school and classroom environments. Tai (2013) suggests that there is a paucity of TPACK studies focused on technology integration in classroom practice. Jaipal and Figg (2010) concur as they describe the majority of TPACK studies as biased towards pre- and post-surveys and post-interview data collections which tend to rely on teacher self-report as discussed earlier in this chapter. The authors lament the lack of data that actually describes what TPACK '*looks like in practice'* (p417) or what are the specific characteristics of the individual TPACK components as teachers apply them in the classroom and school context.

Tai (2013) reports on studies that demonstrate the emerging role of 'design thinking' in professional development programmes to enable teachers to learn by doing TPACK in authentic settings and not by learning about TPACK. Lee and Kim (2014) describe design as 'a process of solving problems that are complex and ill-structured' (p440). They describe *learning by design* as a strategy allowing teachers to take the role of designers in 'an authentic environment' to experience in collaboration with other teachers 'the complexity of learning and teaching contexts' when designing, implementing, reflecting on and re-designing technology integrated lessons (ibid). Here Koh *et al.* (2015b) point to conceptions of design thinking as integrating 'a transformative view of TPACK' as 'design thinking involves teachers drawing upon various forms of TPACK to create new forms of TPACK for 21st century learning' (p3).

Jaipal and Figg (2012) pioneered a 'TPACK-in-Practice' framework for developing 'teacher 21st century knowledge' (p4683) in designing and implementing technology–enhanced lessons in actual classroom practice. The framework emerged from the authors' preservice and in-service studies on TPACK knowledge teachers use in practice associated with the technological knowledge components and intersections of TPACK where technology is infused (TK, TCK, TPK, TPCK) (Jaipal & Figg, 2010; Jaipal-Jamani & Figg, 2016).

The 'TPACK-in-practice' framework provided a basis for the authors to develop teacher education workshops integrating four key design elements, namely:

a) modelling a technology enhanced activity type (TCK)[8]
b) integrating 'pedagogical dialogue' in a modelled lesson (TPK)
c) developing TK in context through tool demonstration (TK)
d) applying lessons design of an authentic learning task (TPACK)

(Figg & Jaipal, 2012, p4685)

It is a model that echoes design thinking guidelines in the general literature to prepare teachers for effective technology integration in authentic practice, namely: modelling theory into practice, learning technology by design, and collaborating with peers in reflection on practice and design ideas for improving practice (Table VI).

Table VI - Guidelines for Learning by Design

Guidelines	Literature
1. Modelling how to use technology	Develop exemplary curriculum materials • to provide teachers with theoretical and practical insights of technology enhanced, learner-centred lessons and hands-on tools • for immediate try out and application in practice Agyei and Voogt (2011), Kafyulilo, Fisser and Voogt (2013)
2. Learning technology by design and re-design	Engage teachers in learning by design to develop technology enhanced lesson plans, resources, authentic problem solving tasks and projects for subject matter teaching • to move teachers away from traditional epistemologies where the primary concern is true or false values of knowledge claims (Chai *et al*., 2013) • to new creative spaces working together to reconsider teaching of their subjects, to challenge and move their thinking forward (Simmie, 2007)
3. Collaboration with peers	Provide opportunities for teacher reflection in the context of authentic classroom settings on how technology can 'fit' into instructional style and into the school curriculum (Muellar *et al*., 2008) • to develop teacher capacity for reflection in-action • to develop teacher 'talk-back' capacity to refine the problem framing of their lesson design and initial solutions (Schon 1983, cited in Koh *et al*., 2015a)

In the Kenya SIPSE professional learning programmes the instructional design of each module was organized in four units aligned to the *TPACK-in-practice* model pioneered by Figg and Jaipal (2012). A critical component of the module structure was the sequencing of design, implementation and reflection activities to develop teacher collaborative knowledge building and design capacities for TPACK application to support and innovate STEM classroom practice. The module design also drew

[8] TPACK activity types provide examples of technologies to support activities across the curriculum to 'help teachers successfully integrate technology into their practice' (Harris, Mishra and Koehler, 2011, p397); activities are categorized into 'knowledge building and knowledge expression' types (ibid. p402); and 'convergent and divergent knowledge building' types (Blanchard, Harris and Hofer, 2011, p409)

on elements of Angeli and Valanides's (2009) proposition of an ICT addition to the TPACK framework constructs (ICT-TPACK) to take into account 'the important issue of tool affordances' (opportunities and barriers) and other factors such as 'teachers' epistemic beliefs and values about teaching and learning' (p157) discussed earlier, that can influence their design thinking and decision making on the object and use of technology in practice. Table VII and Appendix 1.2 present an overview of the online and school-based SIPSE TPACK-in-practice design that underpinned the professional learning programme.

Table VII - SIPSE TPACK-in-practice Design

TPACK-in-Practice Unit Online & School Based Activities	TPACK-in-Practice Activity Descriptions	TPACK-in-Practice Components	Timeframe for Unit Implementation
Unit 1 - **Lesson case studies** - Discussion forum	**Model exemplary curriculum materials** in the form of technology enhanced STEM lesson plans and resources	TCK (R)	1 week
Unit 2 • **Pedagogical dialogue** • Discussion forum & chats	**Pedagogical dialogue** on strategies and technology use that can support student STEM concept understanding and application	TPK (R)	1 week
Unit 3 - **Computer practical** - Online and school based technology support	Build **teacher capacity in use of ICT tools** from basic to advanced skill levels and to prepare lesson e-resources with use of tools	TK (D)	1 week
Unit 4a: • **Teacher design teams** • Lesson planning	**Technology enhanced lesson planning** for didactic/ problem-based / project-based STEM lessons	ICT-TPACK (D)	1 week
Unit 4b: • **Classroom try-outs** • Teacher reflection	**Peer-to-peer lesson observations** and post-lesson reflection focused on design and re-design ideas for lesson improvement	ICT-TPACK (IR)	1 week
D = Design; I = Implementation; R = Reflection			

The SIPSE combined ICT-CFT and TPACK frameworks formed an *ICT-CFT-TPACK-in-practice* model synergy that comprised the essence of the SIPSE professional learning approach (Figure 2.3). As teachers tried out technology integration throughout the two cycles of their professional learning journey, the expectation was for parallel shifts or changes in pedagogical practices - from teacher conventional 'signature pedagogies' towards more transformative technology enhanced 'future pedagogy practices' to support 'STEM content' in teaching and learning.

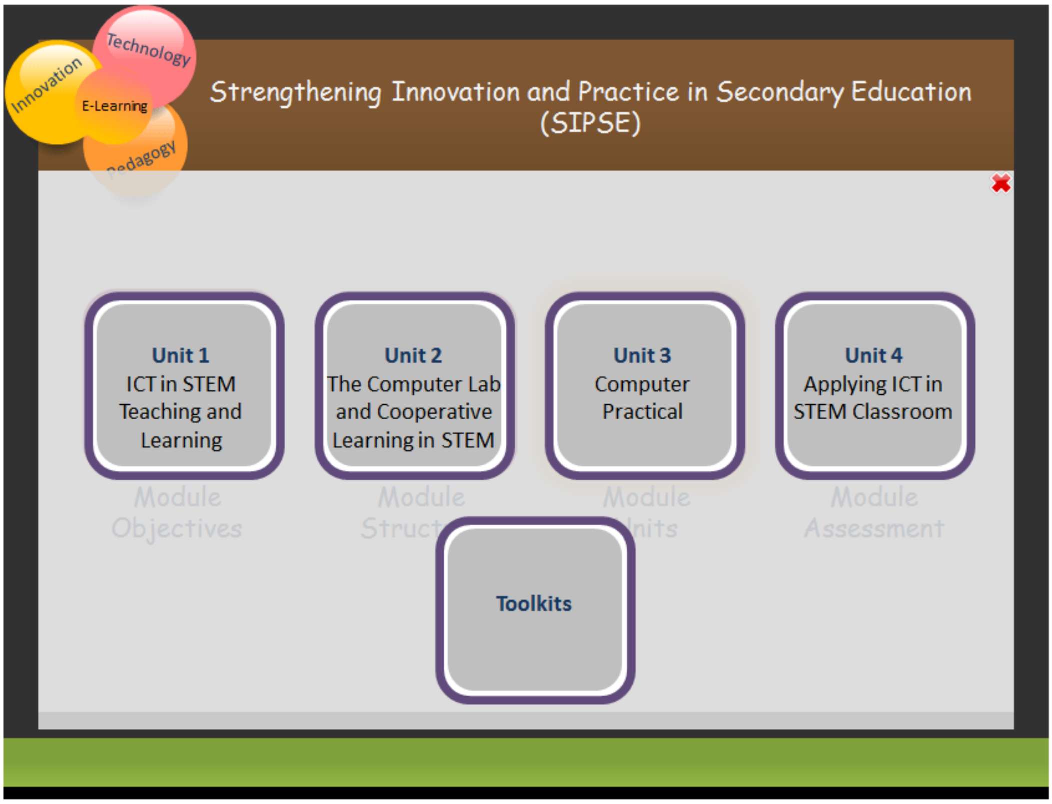


Figure 2.3 - SIPSE Module Units (Source: SIPSE CD, 2014)

In sum, the TPACK lens provides the second layer of the research conceptual framework for appraising the SIPSE intervention programme. The focus is to examine whether and to what extent teacher design thinking, planning and application of ICT in practice changes over time as they move through two cycles of the SIPSE *ICT-CFT-TPACK-in-practice* intervention.

2.3.3 The Activity Theory Lens

Activity Theory (AT) (Vygotsky, 1978; Engeström, 2001, 2003) presents a theoretical framework that is widely applied to study technology-based learning and working situations (Issroff & Scanlon, 2001). The use of an AT framework can both generate clarity of the environment and make more explicit the assumptions, values and beliefs that underpin organizational, technological and pedagogical perspectives of ICT integration and change processes (Demiraslan & Usluel 2008; Robertson, 2008). In this AT can be used to understand the nuanced processes of change or transformation within a classroom activity system when a new technology tool is introduced (ibid; Robertson, 2008). The AT framework can assist in understanding how the object of technology use by teachers can or may change over time as they engage in professional learning journeys (Hardman, 2005).

Activity Theory is derived from Vygotsky's (1978) ideas on mediation and learning. Vygotsky viewed human consciousness as social and learning by implication as characterized by social interaction with peers or more knowledgeable others. Social interaction is mediated by the use of tools (mediating tools) that can be conceptual and practical. In education settings 'conceptual tools' can be described as principles, frameworks, ideas or beliefs about teaching and learning that guide or mediate decision making in educational instruction or management. 'Practical tools' such as textbooks or computer hardware and software are tools that subjects (teachers or learners) use practically to mediate teaching and learning (Zevenbergen & Lerman, 2007; Terpstra, 2015).

A first generation school of activity theory has developed around Vygotsky's proposition that humans use mediation of tools to both change their world and are themselves transformed by tool use (Hardman, 2005). It is a proposition that paves the way for understanding learning as transformation rather than transmission (Figure 2.4).

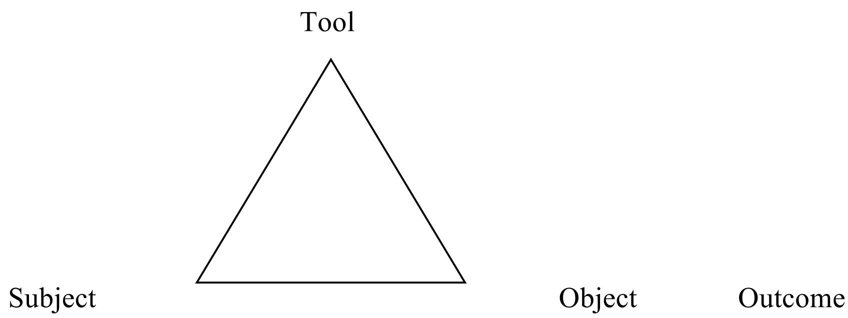


Figure 2.4 - First Generation Activity Theory (Source: Vygotsky, 1978)

It is within the AT frame for transformational learning that Vygotsky conceptualized the notion of the 'zone of proximal development' (ZPD) (1978, p86). The ZPD can be described as a 'space' where gaps between assisted and unassisted knowledge building can be mediated by tools and more competent peers. It is a space that has been appropriated by education and teacher education lobbies for learning and reflection through 'a lot of toing and froing backwards and forwards as thoughts, ideas and social interactions mature' (Gray & Mac Blain, 2012, p74). It is a space that can contain asymmetrical and symmetrical dimensions for learning and co-learning among teachers and students bringing together 'different ideologies, perspectives and potentials for new development and transformation' (Roth & Redford, 2010, p306). More importantly in terms of 'how' change and transformation can occur, it is a space where contradictions, conflict, disruption and discontinuities are seen as inevitable but useful tools between 'present and foreseeable future' activities – 'illuminative hinges' that can create opportunities for expansive learning (Foot, 2001, pp68-70).

Paavola *et al*. (2004) summarize the ZPD space in education as serving a higher purpose for the 'pursuit of newness' or 'knowledge building and knowledge creation' as opposed to 'knowledge *per se*', where the learning community is in 'continuous effort of going beyond current levels of accomplishment' (p567). The authors explicate the dynamics within the ZPD innovation and change space as revolving around teacher 'tacit knowledge' discussed in the previous section, as articulated in their 'subjective insights, intuitions, hunches or ideas' (p571). The authors argue that a crucial basis for innovation and change is the externalization of tacit knowledge around shared objects of activity among the co-learning resource of the professional community in order to develop solutions to problems and challenges. Yet Moreno (2005) observes that while most knowledge about teaching is tacit in the form of teachers' 'know how' (p7), it is a form of knowledge that is 'seldom documented' and 'made explicit' (p10) in teacher development. In this regard O'Sullivan (2005) sees teachers 'know how' as grounded in 'common sense knowledge' that researchers (and policy makers) should seek 'to validate rather than dismiss' (p306).

Hargreaves (1999, citied in op. cit.) proposes the idea of the "knowledge creating school" as a dynamic model for 'co-learning professional development' among practising teachers in a 'conscious effort to articulate teachers' professional experiences (and tacit knowledge) into shareable knowledge within and between schools' (p582). Engeström *et al.* (2014) see the school as a ZPD space and potential 'change laboratory' to promote locally constructed whole school innovation centred on a 'practice-based approach'. It is an approach, however, that should be supported with 'theory laden' tools to confront practitioner 'tacit understandings of everyday practices that are often insistently repetitive' (p8). In this Schleicher (2015) cautions that school change and innovation approaches need to engage with the 'pedagogic cores' at the heart of school and learning environments - which require 'transforming organizational relationships and dynamics to make them relevant for the 21st century' (p62). Schleicher suggests that what is needed is a rethinking of the kind of organizational patterns that are the 'backbone' of most schools today, as in: the 'isolationism' and 'privatism' of teaching in individual classrooms separated from other classrooms (Fullan, 2007, p149); each classroom with its own teacher, the familiar fixed timetables and bureaucratic units of curricula, the traditional approaches to teaching and classroom management (Schleicher, 2015). Engeström *et al.* (2014) would concur on the challenges of 'institutional complexity' and propose the need for a framework to engage multiple stakeholders (practitioners, administrators, policy makers, researchers) in research and development on 'collective activity about collective activity' (p8).

It is within these broader frames of an extended system for learning, co-learning, re-thinking and re-grouping practices that a second generation of activity theory has been developed by Engeström (1987, 1996, cited in Robertson 2008), which centres on the proposition of an object-oriented tool-mediated AT transcribed as a collective 'Activity System' (AS). A key feature of the activity system is the conceptualization of all human activity as the interaction of six inseparable and mutually constitutive elements: *subjects, tools, object and outcome, rules, community* and *division of labour*. The *community* or a group of people who share the common *object* (or problem space) and who use the *tools* to act on that space transforming it (and being transformed by it); the common object is subject to change and is difficult to pin down; relationships in the system are driven by *rules* which both afford and constrain behaviour; the *division of labour* within the system describes how tasks are divided horizontally between community members as well referring to any vertical division of power and status (Centre for Activity Theory and Developmental Work Research, 2003) (Figure 2.5).

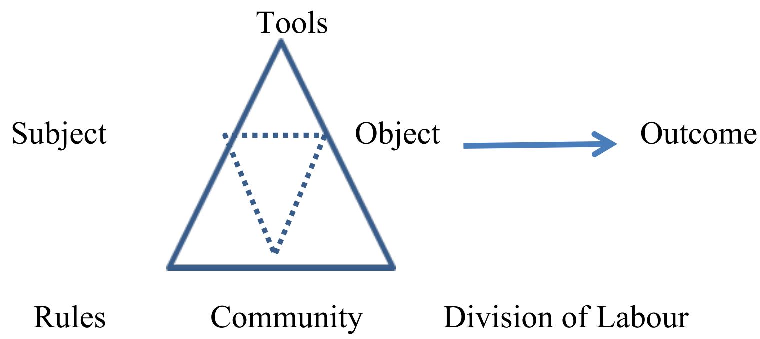


Figure 2.5 - Second Generation Activity Theory (Source: Engeström, 2001, 2003)

The key process of learning and innovation within the activity system is the development of shared or common objects of activity (Hardman, 2005; Engeström *et al.*, 2014). Hardman (op.cit.) explains how the computer is commonly introduced as 'a common tool' in education 'activity systems' to transform students' motivation for learning in lessons. The same computer 'tool' can quickly become the 'common object' or 'problem space' to be acted on by teachers to transform teaching and learning and to be transformed over time (p262). The author asserts that 'systems change when their objects change' (ibid.).

The usefulness of the AT lens to examine ICT integration in education has been demonstrated in multiple studies including research by Lim and Hang (2003) to appraise ICT integration in schools in Singapore, by Yamagata-Lynch (2003) to examine a Technology Professional Development programme in schools in the United States over a year-long implementation, by Hardman (2005) to understand teachers' perceptions of computer usage in primary schools in South Africa, by Hooker (2009) to map processes of multi-stakeholder dialogue on ICT use in teacher professional development in Rwanda, and by Engeström *et al*. (2014) in a change laboratory for examining the challenges and potentials of ICT integration among a heterogeneous group of teachers in secondary school teaching and learning in Botswana.

However, Yamagata-Lynch (2003) reveals limitations in the AS triangular framework to capture the complexity of human interaction within its 'static and seemingly structured nature' where the 'diagramming of Activity Systems' has a tendency to 'freeze frame the action taking place' (p117). Hammond (2013) would seem to concur noting the AS tendency towards a 'formulaic focus on constraints of change and limits of agency rather than emergent practice' (p2). The author suggests a need to explore a more nuanced view of system potentials rather than a focus on the deconstruction of its properties. This would be a return to the notion of examining the 'affordances' that actors perceive in newly deployed technology rich environments which can offer limitless 'opportunities' for change as well as limiting 'constraints' that inhibit teacher agency in engaging with new technologies.

AT can thus be summarized as a framework and space that may need more flexibility to release its potential for examining the dynamic interplay between its system components. Notwithstanding these limitations, it is a framework that can be adapted, improved and indeed integrated with other frameworks for facilitating multi-dimensional processes for investigating and integrating ICT in education and teacher professional learning. In this study the AT lens provides the third and final layer of the research conceptual framework to guide the process of examining the SIPSE intervention. It is a lens that can examine school and teacher community historical development, perceptual understanding and applications of ICT as a tool and problem space for improving and innovating STEM teaching and learning processes.

2.4 The SIPSE Model of ICT Integration - ICT-CFT-TPACK-in-Practice

The combined lenses of ICT-CFT, TPACK and AT create a conceptual framework for examining the SIPSE teacher professional development journey over time at two levels, as in: a 'technology literacy' level of ICT use to support existing 'signature' or didactic pedagogical strategies in STEM subject teaching; a 'knowledge deepening' level of ICT use to promote innovative practice within newer settings of pedagogical strategies centred on problem-based and project-based learning (PBL) techniques (Figure 2.6).

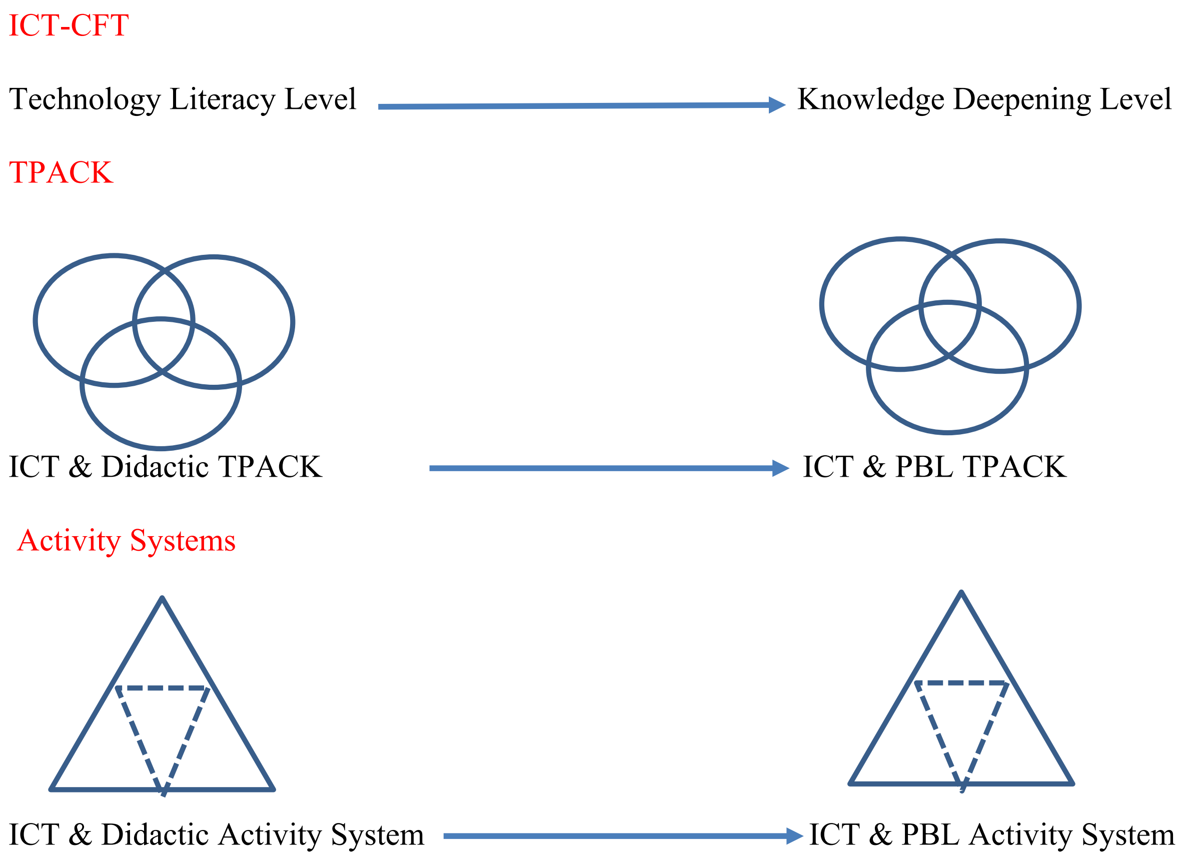


Figure 2.6 - SIPSE ICT-CFT-TPACK-in-practice (Adapted: Engeström, 2001, 2003; Koehler & Mishra, 2008; UNESCO 2008, 2011)

The TPACK lens focuses attention on teachers' knowledge growth as they explore and design technology integration to support STEM content representation and pedagogical strategies from didactic to problem and project based learning approaches, throughout the two cycles of their professional learning journey. While the TPACK lens can thus explicate 'what' knowledge the teachers are developing, the Activity Theory lens can assist in understanding of 'how' the teachers' TPACK design knowledge develops throughout the two cycles within the affordances (opportunities and constraints) of their school contexts. The AT lens can further assist in clarifying how the historical and cultural activities of traditional school settings can impact the trajectory of teacher capacity development for ICT use – from supporting traditional didactic norms towards supporting new constructivist problem- and project-based scenarios for teaching and learning.

Terpstra (2015) proposes the employment of a 'TPACKtivity lens' combining TPACK and AT for tracking and explicating changes in teacher knowledge and development in professional development programmes. The combined lenses present a more powerful tool for examining the 'what' of teacher design knowledge development (TPACK) and the 'how' implications for 'fitting' teacher new design ideas within the traditional contexts of their school and classroom practices (AT).

In this study the TPACKtivity lens is employed in order to map not only 'what' and 'how' but also 'when' and 'where' considerations of teacher technology use and changes in their perceptions and practices of technology use throughout the two cycles of the SIPSE intervention As such the justification for integrating the TPACKtivity lens is its capacity to offer 'a way into the complexities of [teacher] knowledge development and enactment, offering new insights for teacher education programmes, as they seek to capitalize on technologies' affordances' (ibid., p86) (Figure 2.7).

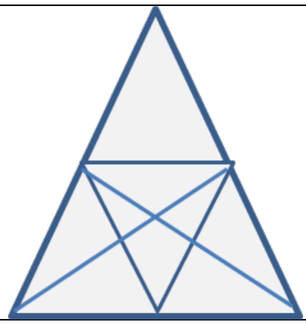
TPACKtivity Lens: SIPSE ICT-CFT-TPACK-in-practice			
• **AS:** Subject, Tools, Object, Rules, community, Division of Labour, Outcome • **ICT-CFT:** Understanding ICT in Education (Policy), Curriculum & Assessment, Pedagogy, ICT, Organization and Administration, , Teacher Professional Learning • **TPACK:** ICT-TK, TK, TCK, TPK, TPACK, ICT-TPACK			
	Tools **ICT** **TK**		
Subjects **Teachers** **Head Teachers**		**Object** **Understanding ICT use in Education (Policy)** **ICT-TK**	**Outcome** **Model of 21c Teacher Professional Learning** **ICT-TPACK**
Rules **Curriculum & Assessment** **TCK**	**Community** **Teacher Design Teams of STEM & Other Subjects** **Teacher Professional Learning** **TPACK**	**Division of Labour** **Pedagogy, Organization & Administration;** **TPK**	
Cycles • Cycle 1: Technology Literacy: *ICT and Didactic Teaching* • Cycle 2: Knowledge Deepening: *ICT and Problem-Based and Project-Based Learning*			

Figure 2.7 - TPACKtivity Mapping: SIPSE ICT-CFT-TPACK-in-practice (Adapted: Terpstra, 2015)

In summary, this chapter examined the literature around global, regional and national agendas driving the use of ICT in Education and ICT in STEM subject teaching to address a new urgency for quality learning and skills development relevant to the needs of emerging knowledge economies and societies. A specific focus in the literature review was the drive towards reconceptualising teacher professional development for ICT use. The review revealed gap areas for conceptual frameworks to enable deeper research and understanding on the relationship between teacher development and effective ICT integration in school and classroom practices. In this regard the literature review explicated three frameworks and lenses of ICT-CFT, TPACK and AT that have emerged in the field for understanding, designing and evaluating the impact of teacher professional development interventions for ICT use in the context of school and classroom practices. The chapter concluded with an overview of the ICT-CFT, TPACK and AT convergence into a TPACKtivity lens as a consolidated conceptual framework for the study inquiry - to examine and understand the complexities of teacher professional learning for ICT use in STEM within the context of Kenya secondary education school and classroom practices. In Chapter Three the methodology for appraising the SIPSE professional development intervention is presented.

CHAPTER 3

Research Methodology

3.0 Introduction

As outlined in chapter one, the aim of this study was to critically appraise the innovation model in relation to teacher development for ICT use in classroom practice associated with the Strengthening Innovation and Practice in Secondary Education (SIPSE) programme over its two year pilot phase. This chapter commences in setting out the theoretical frameworks of post-positivist symbolic interactionism that guided the inquiry's qualitative orientation; within this framework it outlines the constructionist lens that was used. The chapter follows with an outline of the Design Based Research methodology that was adopted and the rationale for its adoption. The chapter continues by presenting the details of ethical considerations, sample, methods, data collection and analysis that were utilized. This is followed with a discussion on considerations of positionality and validity associated with the researcher's dual roles as designer and researcher in the inquiry.

3.1 Research Questions

It was discussed in the literature review that a key focus in the research conceptual framework was to track the object of teacher perceptions in relation to ICT use in STEM. To ensure the research aim is adequately addressed, three key research questions were drawn up:

1. What is the object of ICT integration in teaching and learning perceived by head teachers and teachers during the two cycles of the SIPSE pilot programme?
2. What are the characteristics of teacher design for ICT use in STEM teaching and learning mid-way through the SIPSE pilot programme, as evidenced in their approach to problem-based activities?
3. What are the characteristics of teacher design for ICT use in STEM teaching and learning at the end of the SIPSE pilot programme, as evidenced in their approach to project-based activities?

An underpinning question that is addressed in the final conclusions chapter is what is the product or outcome of the SIPSE professional development intervention and how might it contribute to the theory and inform the practice of professional development programmes for ICT use in classroom practice.

3.2 Theoretical Framework and Research Paradigm

The purpose of research is to generate theory and knowledge. The purpose of educational research is to develop evidence-based outcomes in the form of theories and new knowledge to inform educational policy and practice (Stenhouse, 1975 cited in Whitehead & McNiff, 2006). Fullan (2007) would suggest that educational research in the current age of 'relentless ubiquity of educational reform' (pxiii) needs to be focused on deeper levels of change versus reforms. He contends that research should focus on how to improve the circumstances and conditions of individuals (teachers, school leaders, students, school communities) as well as defining policies and resources for school settings. Sugrue (2008) would concur noting that in the knowledge age the need is for appropriate educational research resourcing and support to enable the teaching profession (interfacing the 'plate tectonics' of educational change) to 'reach far beyond the technical tasks of producing acceptable test results, to pursuing teaching as a life shaping, world-changing social mission' (p49).

The challenge in education research lies in what Sugrue (ibid.) describes as the 'paradigmatic wars' that are manifested in the 'often polarised' research ideologies that seek to shape the future of education (pp50-51). The origins of the paradigmatic wars can be sourced to ancient discourses and debates that have continued to define and challenge philosophical world views to the present age (Schon, 1995; Pring, 2000; Sugrue, 2008) about 'the very nature of knowledge in relation to what it is and how it is acquired' (Whitehead & McNiff, 2006, p33). Lincoln and Guba (2005) describe the paradigmatic divisions as dualist in nature centred around the 'conventional texts' of the scientific 'quantitative' methods and positivist paradigm versus the 'messy texts' of the post-positivist, post-modernist 'qualitative' constructivist paradigm (p184). The latter breaks the boundaries of the conventional through 'searching out and experimenting with narrative, voice and the storied variation of human experience' (ibid.). Habermas (1972, cited in Cohen *et al.,* 2007) moves beyond the dualist articulation to define three paradigmatic research fields related to 'technical' (prediction and control), 'practical' (understanding and interpretation) and 'emancipatory' (emancipation and freedom) approaches for generating 'worthwhile knowledge' (p18) as presented in Table VIII.

Table VIII - Three Research Paradigms

Paradigm domains	Paradigm approach parameters
Technical Empirical-analytical (positivist or objectivist) research paradigm	Emphasis on • Quantitative approaches 'where ideas must be subjected to the rigors of testing before they can be considered knowledge' • Instrumental knowledge that is only acceptable 'when gained through experience and the senses' (Bryman, 2012 p23)
Practical Hermeneutic (interpretative or constructivist) research paradigm	Emphasis on • Qualitative approaches which are premised on the view that 'reality is socially constructed' • Social perspectives which 'seek to understand situations through the eyes of the participants' (Berger and Luckmann 1967, cited in Cohen *et al*.,2007, p27)
Emancipatory	Emphasis on praxis in its concern for

Paradigm domains	Paradigm approach parameters
Critical (emancipatory or subjectivism) approaches	• action that is informed by reflection in its aim to emancipate (Kincheloe 1991 cited in Cohen *et al.,* 2007, p28) • dual intentions to expose dominating power structures and bring about social justice (Habermas 1979, cited in ibid.)

There is a sense in all of the debates of a growing crisis in the education field that is manifested in at least two fronts. On the one hand the 21st century new development policy demands for building knowledge-based societies and economies has presented a parallel urgency for educational research to build understanding of education practice and delivery that is relevant for the new knowledge age (Sugrue, 2008). On the other hand the paradigmatic divisions and plethora of approaches in the eyes of some have rendered much educational research today to be unsatisfactory and fragmented (Hammersley, 2004). Sugrue (op. cit.) surmises the divisions as creating a 'balkanization' in the field (p50). Hammersley (op.cit.) assesses the development of knowledge through educational research to be 'minimal at best', and the current state of the research field as creating 'serious problems in teaching, since difficult decisions have to be made about which of a myriad of approaches to introduce to students, and how to do this' (pp142–143).

Arising from these ontological considerations are questions of epistemological approaches adequate to address the dilemmas of educational research in general. In the context of this inquiry the questions centre on approaches adequate to appraising the SIPSE teacher professional development intervention. It is an inquiry that is straddled between the research debate dilemmas for assessing whether the intervention is 'something that works' (Nicolopoulou & Cole, 2010, p69) and for creating new knowledge for improving models for ICT integration that are responsive to the needs of a rapidly developing Kenya knowledge-based economy and society.

3.2.1 A Qualitative Constructivist Orientation

In defining parameters for research into teachers' classroom practices, Groth *et al.* (2009) relate the use of conceptual framework lenses to 'identify theoretical constructs for attention'. The authors explain the affordance of such frameworks for enabling investigation into the 'complex interrelationships among the different aspects of teachers' knowledge and their relationships to teaching' (p394). The present inquiry drew on the triad of ICT Competency Framework for Teachers (ICT-CFT), Technology, Pedagogy and Content Knowledge (TPACK) and Activity Theory (AT) conceptual frameworks and lenses as described in the literature review.

It is the ‘semiotic processes’ or ‘mediated action’ (Yamagata-Lynch, 2003, p101) emanating from the AT lens for context-specific shared meaning-making among the school community participants, that informed researcher decisions to position the research inquiry in a ‘qualitative’ orientation. The focus of the inquiry on understanding changes in participant perceptual and observed understandings of ICT use in the context of their school and classroom settings required what Hardman (2005) describes as an ‘explanatory framework’ that ‘emphasizes the emergent nature of mind in activity and acknowledges the central role of interpretation’ (p259). It is an epistemological orientation that is echoed in literature discourses on ‘cognitive’ and ‘linguistic’ turns that gathered moment in social science research paradigms in the latter part of the twentieth century (Reason & Bradley, 2008, p5). The ‘turns’ formed part of a post-modernist paradigmatic shift that prompted reactionary anti-positivist views on theories of knowledge acquisition (ibid.). They emerged from earlier research genres inclusive of Activity Theory and its antecedent social science theory of ‘Symbolic Interactionism’ developed from the foundational work of George Herbert Mead (1863-1931) (cited in Berg, 2009, p8) - the latter theory locating human behaviour as dependent on learning rather than biological instincts. In this, the thrust of the ‘turns’ discourse centres on a recognition of ‘cognitive schemata’ or ‘mental models’ (Adler & Adler, 2008, p1) and learning communicated through ‘linguistic symbols’ the most common being language (op cit., pp9–13), for enabling processes of deep reflection and sense-making of a phenomenon such as new technology integration in educational practice.

In these meaning-making frames, the triad of ICT-CFT-TPACK-AT frameworks that underpin this inquiry are utilized to provide what Bryman (2012) describes as ‘sensitizing concepts’ central to the qualitative research orientation as opposed to ‘definitive concepts’ associated with quantitative research (p388). It is the sensitizing concepts that offered a reference and a ‘general sense of what to look for’ in approaching the research design for uncovering multiple discourses of participant perceptions, understanding and meaning-making as they engaged in the SIPSE programme intervention. It is these concepts that further defined the epistemological thrust of the inquiry as situated in a qualitative constructivist approach that seeks to co-construct knowledge and meaning with participants in educational settings.

However, there was a caveat in the research orientation to address the research questions in a way that investigates the challenges of teacher ‘take up’ (Hammond, 2013, p209) of ICT in classroom settings for creating ‘usable knowledge outcomes’ (The Design Based Research Collective, 2013, p2) that can improve practice and contribute to policy. It is a caveat that was addressed by the methodological approach adopted in the inquiry, centred on design-based research as outlined in the following section.

3.2.2 Design Based Research

Anderson and Shattuck (2012) describe a design-based research (DBR) approach as a research methodology that can bridge the chasm that exists between research and practice in formal education systems. DBR is defined by Wang and Hannafin (2005) as a 'systematic and flexible methodology' which aims to improve educational practice through 'iterative analysis, design development and implementations' that link together the value chain of researchers and practitioners to the 'real world settings' of school and classroom contexts (p3). Lewis, Perry and Murata (2014) describe the DBR process in terms of 'cycles of design, enactment, analysis, and redesign' that can enable researchers and practitioners to 'hone an innovation while also building theory about "how it works" and not simply to 'empirically tune "what works"' (p5). In this regard, the Design Based Research Collective (2003) advocate the arrival of DBR as an important methodology for understanding 'how', 'when' and 'why' educational innovations work in practice (p5). These are questions integral to the SIPSE intervention and frameworks underlying the research inquiry with an added interrogative of 'what' would constitute innovative practice as perceived, observed and applied by teachers in the iterative cycles of their professional learning journey.

Anderson and Shattuck, (2012) credit the origins of DBR as emanating from the work of Ann Brown (1992, cited in ibid.), an American researcher who considered that an 'effective intervention' should be able to migrate from an 'experimental classroom to average classrooms' operated by 'average students and teachers and supported by realistic technological and personal support' (p16). Leinonen *et al*. (2008) explain that while the DBR is derived from social science and educational research genres, the 'context is design' and the hermeneutic cycles 'increase researchers' and designers' understanding of the context and factors in all the phases' (p1). The authors further argue that the result of design is a 'product' and a key question relates to how to create 'meaningful products' in educational research (ibid.). In this Nicopoulou and Cole (2010) relate the 'core element' of DBR as an investigation of 'cognition' in context (p9). The authors contend that the 'enormous complexity' of the learning ecology requires a conceptualization of context in terms of activity systems associated with Activity Theory (p68). The conceptualization of context, cognition and product as outcomes is central to this research inquiry for uncovering the complexities inherent in what Cowan (2015) describes as the ecology of teacher professional learning. The opportunities for focusing the research on the professional development intervention in the context of average classroom activity systems supported by the norms of technology and technical provision within the Kenya education system, was also a critical rationale for adopting a DBR approach.

Despite the research extolling its benefits, there have been a number of critiques of the DBR approach. Nicolopoulou and Cole (2010) point out that while many DBR researchers assert the learning ecology and its context as co-constituted, ‘many of them tend to conceive of context as somehow distinct from the learning ecology’ (p69). A number of authors describe complexity and inherent bias of the researcher as developer of the design intervention while also trying to understand its enactment in context (The DBR Collective, 2003; Sandovel & Bell, 2010; Anderson & Shattuck, 2013). Anderson and Shattuck (2013) discuss the daunting task of deriving generalization results ‘from the diverse types and contexts of DBR study’ (p22). Here the DBR Collective (2013) point out DBR reliance on techniques associated with other research paradigms ‘like thick descriptive datasets, systematic analysis of data, and consensus building within the field around interpretations of data’ (p7). In this there is the risk of what Bruan and Clarke (2006) describe as an ‘anything goes’ syndrome associated with qualitative research in general, which can undermine the unique claims of DBR as a rigorous product driven alternative to close the ‘credibility gap’ (Sandovel & Bell, 2004, p199) in the educational research field.

Notwithstanding the critique, DBR in all its complexity appeared to be an appropriate approach to document this inquiry into the SIPSE programme. A critical aspect of the approach is addressing the research questions in relation to the enactment, outcome and product of applying the SIPSE ICT-CFT-TPACK-in-practice frameworks, the complexities of the interplay of elements in classroom and school activity systems and the implications for policy and practitioners for improving future iterations of the intervention. Table IX presents an overview of processes involved in the DBR approach based on patterns of its application derived from the literature and its adaptation for the purposes of this inquiry.

Table IX- Design Based Research Processes (Sources: Nicolopoulo & Cole, 2010; Anderson & Shattuck, 2012)

SIPSE *Pilot Project* Design Processes	Inquiry *Design Based Research* Processes
1. Assessment of the local context informed by the literature and other contexts 2. Creation of design intervention to overcome some problem or create an improvement in local practice 3. Multiple iterations – cycles of design, curriculum enactment, data analysis and redesign	1 Multiple methodologies - using a variety of research tools and techniques 2 Collaborative partnership between researcher and practitioners – negotiating problem identification, design and construction, implementation and assessment 3 Evolution of design principles – and enhanced solution implementation – not in the form of grand

SIPSE *Pilot Project* Design Processes	Inquiry *Design Based Research* Processes
	theories – but more intervention adjustments so as to maximize learning

This inquiry as noted in chapter one was conducted in research schools that were part of the larger SIPSE pilot programme which was in progress prior to and during the study. Thus, Table IX delineates the Design Based Research processes that were conducted as part of the pilot programme roll-out, and the processes that were the focus of this inquiry.

The *SIPSE Pilot Programme Design processes* included: 1) researcher work with project technical team and national expert working groups on needs assessment, contextualization and prioritization of ICT-CFT competences for teacher professional development; 2) researcher work with programme and national teams in instructional design and development of intervention modules integrating ICT-CFT and TPACK framework elements; 3) researcher work with programme and national teams in cycles of blended learning implementation with online and school-based support elements.

The *Inquiry Design-based Research processes* included: 1) researcher selection of methods drawing on the affordances of the theoretical frameworks, lenses and tools of the ICT-CFT, TPACK and AT triad that underpinned the SIPSE intervention design; 2) researcher field research with head teachers and teachers in the selected Kenyan research schools to track programme intervention iterations and review with participants' problems and design ideas for enhancing and improving practice; and 3) researcher documentation of the evolving nature of the teachers' design framing of innovative practice as they engaged in two cycles of professional learning activities and of the implications for designing a future model of teacher professional learning.

Appendix 2 shows how the research questions are aligned with the DBR methodological processes and products.

3.3 Research Sample and Participants

3.3.1 Sampling - Selection of the Schools

In this study, a purposive sampling process was conducted to select four research schools from across the twenty SIPSE pilot project schools in Kenya and Tanzania. Cohen *et al*. (2007) describe purposive sampling as 'a feature of qualitative research where the researchers handpick the cases to be included in the sample based on their typicality or possession of the particular characteristics being sought' (p114). The purposive sample was confined to four schools selected from the Machakos and Nakuru county programme zones in Kenya. The schools were selected on the basis of micro characteristics that replicated those of the macro programme characteristics, namely:

- The study schools were located in urban and rural areas
- The student profile was gender balanced – where two boys' and two girls' schools were selected
- The schools had computer laboratories that were used regularly for teaching and learning purposes[9]
- The teacher profile had adequate coverage of STEM specialists[10] – as each school had six teacher specialists in the areas of STEM who could be requested to participate in the project.

A profile of the school settings is presented in Table X based on information provided by school heads during interviews on the school community demographics and ICT resources.

Table X - Profile of school settings, school community and resources

<table>
<tr><th>School Settings</th><th>Urban/ Rural</th><th>Student Gender/ Type</th><th>No Of Students</th><th>No of Teachers</th><th>Support Staff</th><th>Technology in classrooms</th><th>Computer lab</th><th>Other</th><th>Technology in school</th></tr>
<tr><td>School A</td><td>Urban with farm amenities</td><td>Girls boarding</td><td>977</td><td>60</td><td>46</td><td>4 laptops, 4 projectors</td><td>40 computers/ connected to internet</td><td>Use of mobile phones for communication – staff & parents</td><td rowspan="2">Administration, Registry students, examinations</td></tr>
<tr><td>School B</td><td>Urban with farm amenities</td><td>Boys boarding</td><td>1,000</td><td>52</td><td>32</td><td>2 laptops, 2 projectors</td><td>20 computers/ connected to internet</td><td>Extra laptops awarded to school as prizes</td></tr>
<tr><td>School C</td><td>Rural</td><td>Girls boarding</td><td>380</td><td>19</td><td>16</td><td>2 laptops, 2 projectors</td><td>40 computers/ connected to internet</td><td></td><td rowspan="2">Departments have laptops/ teacher own laptops</td></tr>
<tr><td>School D</td><td>Rural</td><td>Boys boarding</td><td>1,000</td><td>45</td><td>35</td><td>4 laptops, 4 projects, printer</td><td>Computer lab / internet (no of computers not stated)</td><td>Teachers excel in KCSE performance given 5 laptops by board</td></tr>
</table>

Source: Head teacher interviews, September 2014

The school heads further highlighted some general information on the cultural-historical context of the school settings. All four schools are public government assisted boarding schools and boast farmland amenities, livestock and produce to supplement school diets and budgets. Schools A and B are part of a network of Kenya's national schools – schools of excellence where students with highest scores in national examinations can gain entry. The schools are also adjacent to each other – almost sharing the same campus while separate facilities are delineated for each. Schools B and C are girls' schools and are relatively new having developed from mixed schools with their counterpart boys' schools within the last two decades. Schools A and D are boys' schools and represented older

[9] All of the SIPSE schools received supplementary deployment of two laptops and 1 projector from the project to encourage mobility of ICT use beyond the computer lab into two of more classrooms.

[10] Science (Biology, Chemistry and Physics), Technology, English and Mathematics (STEM)

established schools with a history that dated back over 80 and 50 years respectively. More specific details of the school cultural-historical contexts are presented in the findings chapter four.

3.3.2 Participants

Cohen *et al*. (ibid.) explain the purpose of a purposive sample is centred on accessing ‘knowledge people’, as in ‘those who have in-depth knowledge about particular issues… by virtue of their particular role, power, access to networks, expertize or experience’ (p115). As this study sought to investigate teacher perceptions, knowledge, and potential pedagogical shifts with ICT use in STEM over time as they engaged in the SIPSE programme intervention, the primary group of ‘knowledge people’ was the 24 SIPSE teachers from the 4 selected research schools. A secondary group of ‘knowledge people’ - but also a critical group for understanding the broader context of the SIPSE intervention in the school setting - was the 4 school heads of the selected schools. Table XI presents an overview of the teacher demographic data (according to the variables of gender, age, qualifications, teaching subjects, and number of years of professional experience) extracted from a TPACK survey conducted among all the SIPSE teacher participants in the first cycle of the project implementation in January 2014.

Table XI - Demographic Profile of Study Teachers

	Frequency	Percentage (N=24)
Gender		
Male	15	62.5
Female	9	37.5
Age		
20 - 29 years	2	9.1
30 - 39 years	10	41.7
40 - 49 years	10	41.7
50 - 59 years	2	9.1
Teaching Subjects		
Science	10	41.7
Technology	3	12.5
English	4	16.7
Mathematics	3	12.5
Science & Mathematics	3	12.5
Technology & English	1	4.0
Years of teaching experience		
Less than 1 year	1	4.5
1 - 5 years	2	9.1
6 - 10 years	5	20.8
11 - 20 years	15	62.5
21 - 30 years	1	4.5
30 years and over	0	0
Qualifications		
Diploma in teacher education	3	12.5

	Frequency	Percentage (N=24)
Bachelor's Degree	18	75.0
Master's Degree	3	12.5

Source: Extract: Demographic Information - Kenya Teacher Participants, Research Purposive School Sample, from *Survey of Kenya and Tanzania Science, Technology, English and Mathematics Teachers' Technological Pedagogical and Content Knowledge (TPACK)* – Cycle 1, January 2014

3.4 Ethical Considerations

Ethics considerations are situated in their simplest terms on an understanding of what is right or wrong, good or bad. However, Bryman (2012) expands on these considerations presenting ethics in 'deontological' and 'consequential' terms (p134). The former clarifies research acts as right or wrong in themselves while the latter examines the exploration of research consequences for guidance as to whether it is right or wrong. Cohen *et al*. (2007) position the issues in terms of a balancing act between the researcher scientific needs in the pursuit of truth and the rights and values of research subjects potentially being threatened. The issues of ethical balance were pertinent to this study in a research design involving participants proactively in the research processes. The cost/benefit of research contribution to future models for professional development and ICT use needed to be carefully balanced with potentials for embarrassment and harm derived from research processes explicating tensions and contradictions as well as opportunities in classroom and school practice and the education system.

In order to protect the research participants, the researcher and the ethical integrity of the research study, there was strict adherence to the Queen's University Belfast, School of Education's Policy and Principles on Ethics in Educational Research, inclusive of two submissions to seek ethical approval from the School of Education Ethics Standing Committee when the researcher identified potential issues in the research design prior to data collections with the research participants (QUB, 2014) (Appendix 6.1). A series of research permissions and license applications were further made to various entities from national to local levels in Kenya, namely: a research license from the Kenya National Commission for Science and Technology (Appendix 6.2); a research affiliation with Kenyatta University, Nairobi, as a pre-requisite for granting of the research license (Appendix 6.3); and research permissions from the Departments of Education in Nakuru and Machakos Counties. Documentation with information on the research purposes and consent forms was circulated to teachers and school heads in each of the four selected schools. Clarification on the research purpose, benefits and potential risks for participant involvement, on arrangements to protect participant confidentially and anonymity, on data use, storage and destruction, on permission for audio recording, as well as explanations on participant right to withdraw from the research study at any time were outlined (Appendix 6.4). In the event all 24 of the SIPSE STEM teachers and 4 school heads gave their consent to participate in the research study. However, while the research permissions and consent processes were rigorous, they caused delays in reaching the target schools and catching the research intervention - which was already in its second cycle by the time the researcher arrived in the field.

3.5 Research Data Collection

The data collection incorporated two tool sets associated with the AT and TPACK lenses underpinning the DBR methodology, namely: an AT instrument set consisting of an interview guideline that was adapted for individual, group interview and questionnaire formats; a TPACK instrument set consisting of a focus group discussion guideline that was conducted following teacher peer-to-peer lesson observation. Each instrument set is presented in Table XII in alignment with the research question it addressed.

Table XII - Data Collection Instrument Set

	Data Collection Instrument Sets	
Research questions	**Activity Theory** individual and group interviews and questionnaire	**TPACK** focus group discussion, peer-to-peer lesson observations
Research Question 1: What is the object of ICT integration perceived by head teachers and teachers during the two cycles of the SIPSE pilot programme?	**Individual interviews:** N=5 head teachers N=1 teacher **Group interviews:** N=3 teacher group interviews with 6 teachers in the first group, 3 teachers in the second group and 2 teachers in the third group **Survey:** N=3 teacher respondents	
Research Question 2: What are the characteristics of teacher design for ICT use in STEM teaching and learning mid-way through the SIPSE pilot programme, as evidenced in their approach to problem-based activities?		**Focus Group Discussions:** N=4 Teacher FGDs with 6 teachers per group **Peer-to-peer Problem-based Lesson Observations:** N=4 lessons viewed by 5 teachers (3 lessons) and 2 teachers (1 lesson)
Research Question 3: What are the characteristics of teacher design for ICT use in STEM teaching and learning at the end of the SIPSE pilot programme, as evidenced in their approach to project-based activities?		**Focus Group Discussions:** N=1 Teacher FGD with 7 teachers **Peer-to-peer Project-based Lesson Observations:** N=3 lessons viewed by 4 teachers (2 lessons) and 1 teacher (1 lesson)

The AT interview tools were primarily directed at school heads and at a second level at teachers if they were available. The TPACK focus group discussion and observation tools were solely directed at teachers. The research data sets were collected over three field visits carried out by the researcher between September 2014 and February 2016. The first field visit coincided as the teachers were being introduced to the problem-based module (September 2014), the second with the project-based module (February 2015) of the ‘knowledge deepening’ course cycle. The last field trip was carried out eight months after the SIPSE intervention pilot concluded (February 2016).

3.5.1 The AT/AS Interview

The interview is probably the most widely employed method in qualitative research according to Bryman (2012) who assesses its flexibility to provide rich detailed answers. Mc Niff, Lomax and Whitehead (2003) similarly extol on the benefits of its use in a variety of research contexts to elicit information, evaluate an outcome but more often to develop a conversation ‘that can lead to enhanced insights for all participants’ (p143). For this reason interviews were used in the inquiry to gain insights through conversations with school heads and teachers about the factors in their classroom, school and education system environments that influenced their take up of ICT in teaching and learning.

The interview schedule was developed around the sensitizing concepts of the Activity Theory (AT) lens. It was adapted by the researcher based on an Activity System (AS) interview framework developed by Mwanza and Engeström (2003, cited in Roberston 2008) to operationalize AT in practice. In order to give the teacher and head teacher participant’s flexibility that is aligned with the DBR approach for their engagement in more ‘open dialogue’ (Leinonen, 2008, p2), the schedule was developed in a semi-structured conversational format that drew from the six elements of the AS framework (subject, tool, object, rules, community, division of labour). For each element a core question was developed to guide the interview with probe questions used to supplement the discussion (Appendix 3.1).

The researcher adapted the interview schedule for use in individual, group, Skype (Appendix 3.2) and questionnaire (Appendix 3.3) formats. Cohen *et al.* (2007) note that group interviews are ‘often quicker than individual interviews and hence are timesaving’ but warn of various disadvantages including a ‘group think’ mentality that can be ‘discouraging [to] individuals who hold a different view from speaking out’ (p273). In the same way the authors highlight telephonic interviewing (and its Skype equivalent) with numerous advantages in terms of speed and cost savings but with critical disadvantages including the prevention of ‘thoughtful or deep answers’ (p380). William and Katz (2001) note similar challenges in the questionnaire tool as having potential to yield more objective data, while lacking in the rich dimension of respondent subjective perspectives.

Notwithstanding the limitations, the researcher decided to use multiple interview formats given the limitation of conducting individual interviews in busy school environments. The necessity to position the interviews either before or after the lesson observation and focus group discussion further limited the scope for the tool use particularly with the teachers.[11] After trying the AT/AS schedule in a group interview format with teachers in the first school visited (School C), the researcher decided not to involve all teachers but to focus on interviewing only the lesson teachers given the extra time required and the potential interference with school activities. Where it was not possible to conduct the interviews with head teachers or lesson teachers during school visits, the researcher conducted them via Skype. Where this was not possible the researcher used the questionnaire format as a last resort.

A total of eight AT/AS individual interviews (five interviews with head teachers and three with teachers), one group interview (with six teachers) and three questionnaires (with three teachers) were carried out in the course of three field research visits to the schools. All head teachers and teachers were represented in the interview schedule with the exception of teacher representation from School D (one of the rural schools) due to time challenges during the field trip and Skype challenges after the field trip. In all the sample size of participants in the AT interview/ skype /questionnaire schedules was four head teachers and twelve teachers. See the mapping of head teacher and teacher participation and sample sizes across all three field trips in Table XIII.

Table XIII - AT/AS Interviews and Sample Size

AT/AS Interviews	Head Teachers	Teachers	Timeline
First Field Trip: Sample size- 4 head teachers and 7 teachers			
Individual interview (face-to-face)	**Schools C and D** Two School Heads		September 2014
Group interview (face-to-face)		**School C: Six STEM Teachers** T1: English/ Literature T2: ICT T3: Chemistry T4: Maths/ Physics T5: Physics T6 : Biology/ Physics	September 2014
Skype Interview	**Schools A and B** Two School Heads	**School B: Science Teacher** T1: Biology	October 2014
Field Trip February 2015: Sample size- 3 teachers			
Questionnaire		**Schools A and B:** Three teachers T1: Mathematics School A T2: English School B T3: Mathematics School B	March 2015

[11] This is to note an added limitation where the researcher conducted the field research while based in Ireland. This had implications for cost and time available for field work which was conducted while the researcher was in the field for organizational work.

AT/AS Interviews	Head Teachers	Teachers	Timeline
Field Trip February 2016: Sample size – 1 head teacher and 2 teachers			
Individual interview (face-to-face)	**School B** One Head Teacher		February 2016
Group interview (face-to-face)		**School B:** Two Teachers T1: English School B T2: Mathematics School B	

The AT/AS interviews (individual face-to-face, Skype and group formats) lasted between one and one and a half hours. The researcher started each session with a question on what head teachers and teachers saw as the object of teaching and learning and ICT integration as a first step for opening up the conversation and gradually unpacking 'other critical characteristics of the [school and classroom] activity systems' (Yamagata-Lynch, 2003, p369). The AT/AS interview process yielded different dynamics in interactive discourse between researcher and participants with the weaker dynamics in the first interviews and strongest emerging in the final end-of-project interviews. This could be attributed to the maturity of trust in the evolving relations between participants and researcher over the field visits or the researcher developing more confidence and capability to 'listen, probe and direct' (William & Katz, 2001, p6) the open-ended flow of the conversation. The weakest domain in the AT/AS instrument set was the questionnaire which was used after the second field visit to capture the perspectives of the three teachers who conducted the project-based lessons. The teacher questionnaire responses were somewhat flat – as in 'disconnected from everyday life' (op. cit. p2) of classroom and school activity systems that was the focus of the AT/AS schedule. For this reason the researcher decided to return to the schools to conduct end-of-project AT/AS interviews with any of lesson teachers and head teachers who were available.

3.5.2 The TPACK Lesson Observation and Focus Group Discussion

The focus group discussion and lesson observation research were designed in tandem to emulate what Lewis, Penny and Murata (2014) report as a 'lesson study' model that can be situated in design-based research 'to test and expand our theories of professional learning' (p6). Lesson study is described by the authors as combining 'live classroom observation as the centre-piece of study' in which a group of teachers 'collect data on teaching and learning and collaboratively analyse it' in a post-lesson colloquium to 'reflect on the lesson and on learning and teaching more broadly' (p3). However, the literature highlights teacher collaboration as rare in school systems where teaching as 'a solo practice profession' is predominant (Asia Society, 2015, p16). Njoroge *et al*. (2016) report on lesson study try-outs in Kenya primary school based in-service where 'the practice of teachers working together as a team in planning and teaching was a new development' (pp13-14). Nevertheless, the lesson study format seemed appropriate for involving the teachers in design-based research processes at classroom level. For this reason it was integrated into the inquiry as a tool set incorporating live teacher classroom observations followed by focus group discussions (FGDs) with teachers and researcher.

Coe *et al.* (2014) comment that while observation and feedback present effective strategies ‘when undertaken as a collaborative and collegial exercise between peers’, the literature indicates ‘the need for challenge in the process’ with possible involvement of ‘principals or external experts’ (p4). In this the focus in developing the schedules was to enable ‘challenging’ collaborative design conversations between the researcher and teachers around the observed lessons. The observation and FGD schedules were designed based on a TPACK observation and interview toolkit developed and tested for reliability and validity by Hofer *et al*. (2010, 2011). The schedules centred on observing and analysing teachers’ applications of content knowledge (CK), technology knowledge (TK), technology content knowledge (TCK) and technology pedagogy knowledge (TPK) pillars in practice – where the instruments were *‘not designed to assess this knowledge directly* but to focus upon the *use* of technology integration knowledge in observable teaching*’* (emphasis stated) (ibid, 2010, p1).

The observation and FGD schedules for the inquiry were developed in a ‘co-constituted’ format (Halkier, 2010, p73) that mirrored semi-structured ‘open communication’ (Leinonen, 2008, p2) question types to promote participant meaningful engagement and interaction. The focus in the observation schedule was to probe teacher contextual observations and meaning making around ‘what’ the TPACK constructs ‘looked like’ in classroom practice (what do you see? what do you think?) (Appendix 4.1). The emphasis in the focus group schedule was ‘what’, ‘why’ and ‘how’ questions (what do you think worked well? And less well? Why do you think it worked that way? How could it work better?) to probe teacher collective reflection around their tacit assumptions and beliefs about teaching and learning and to promote teacher design thinking and ‘theory building’ (Cerbin & Kopp 2006, p254) on STEM teaching and learning with and through technology (Appendix 4.2).

A total of four FGDs were conducted during the first field trip in September 2014 - involving all twenty-four teacher participants (six STEM teachers in each school) following their observations of four problem-based lessons (three in Biology and one in English) in the four research schools. On the second field trip in February 2015 one FGD was conducted with seven teacher participants following their observations of three project-based lessons (two in Mathematics and one in English) in two of the research schools. The first visits involved a day in each school for logistics of researcher presentation to the school head, teacher organization of classroom observation and follow-up FGDs involving researcher and teacher teams. The second visit involved two days due to logistics of teacher preparation and organization of project-based webquest lesson observations over two days with students. Here the teacher FGD was conducted after the second lesson. In all the sample size of teachers participating in observations and FGDs was twenty-four for the first field trip and seven for the second field trip. Table XIV presents a mapping of the teacher participants.

Table XIV - Lesson Observations, FGDs and Sample Sizes

Lesson observations and focus group discussion teacher participants		
Schools	**Lesson Teachers (LTs)**	**Teacher Observers (TO)**
First Field Visit September 2014: Problem-based lessons - Sample size 24 teachers		
School A Urban	LT – Biology	TO 1: Mathematics TO 2: ICT TO 3: English, TO 4: Physics/ Mathematics TO 5: Chemistry
School B Urban	LT – Biology	TO 1: English TO 2: Mathematics, TO 3: ICT TO 4: Physics TO 5: Chemistry
School C Rural	LT – Biology	TO 1: English/ Literature TO 2: ICT T3: Chemistry T4: Maths/ Physics T5: Physics[12]
School D Rural	LT – English	TO 1: English/ Literature TO 2: Mathematics/ Physics TO 3: Biology TO 4: Physics TO 5: Chemistry
Second Field Visit February 2015: Project-based lessons: Sample size – 7 teachers		
School A (SA) Urban	SA-LT Mathematics	SA-TO 1: English SA-TO 2 – Physics/ Mathematics, SA-TO 3– Chemistry SA-TO 4 - Biology
School B (SB) Urban	SB-LT Mathematics	SA-TO 3– Chemistry SA-TO 4 – Biology SA-LT – Mathematics SB-LT - English
	SB-LT English	SA-TO1: English

The choice of lesson subject areas and topics was left to the teachers in the first field visit. The researcher rationale was based on considerations for developing a rapport with the teachers, cognizant of Coe *et al.* (2014) observations that successful engagement requires addressing 'issues of trust, authority, and knowing who is in charge of the information generated' (p26). However,

[12] In school C three of the teachers were not involved in the peer-to-peer lesson observation, but participated in the FGD.

given the preponderance of Science lessons selected by the teachers in the first field trip, the researcher requested the school principals and teachers to organize lessons in Mathematics and English for the second visit. The reduction of schools from four to two by the second visit was based on questions of logistics in terms of geographic distance, time and cost to reach the schools – where the two urban schools A and B based on adjacent campuses provided a pragmatic purposive sample for the second field trip. The reduction of teachers in the second visit was due to school events where four of the teachers in School B and one of the teachers in School A were not available.

Each lesson observation lasted forty-five minutes for the problem- and project-based lessons (with the exception of one eighty-minute lesson).[13] The FGDs followed immediately after the lessons and were conducted in the student vacated classrooms with the teachers and researcher. Each FGD lasted between one and one and a half hours. The researcher's aim in the moderation was to create an atmosphere that was not too 'intrusive or structured' (Bryman, 2012, p508). The aim was rather on enabling 'synergy, snowballing, stimulation, and spontaneity' in the focus group dynamic (Williams & Katz, 2010, p3) where the comments of one teacher could 'encourage a train of thought in another [where teachers] may develop new ideas' (ibid.). Each FGD was initiated with an overview from the researcher on the purpose and focus of the discussion that was followed by the lesson teacher reflection and the general group discussion. There were challenges and differences in the focus group dynamic between the rural and urban schools. These could be attributed to the researcher conducting the rural visits first and the challenges therein of first fielding the tools and moderation processes in the school contexts.[14] A more specific issue was related to apparent cultural norms of deference which featured more prominently in the rural schools. The teachers tended to talk in turn in response to each researcher question and did not seem comfortable with picking up threads for more interactive discussion between teachers. Nor did the teachers seem comfortable with probing challenging questions presented by the researcher which were ensued by longish pauses – that tended to push the researcher into question rephrasing and a more intrusive role. When in one of the urban schools a teacher felt it necessary to apologize to the lesson teacher for raising issues on observed practice, it seemed to point to a precarious imbalance emerging in the discussion flow between critiquing teacher exploration of technology use in practice and critiquing teacher practice. However, the researcher found that working with the cultural norms of deference in terms of giving teachers space to respond in turn in the initial stages of the FGDs, gradually built a rapport of researcher-

[13] The project-based lessons consisted of two separate lessons periods of forty minutes conducted over two days to enable students to complete 'webquest' projects using computer lab facilities in between lessons and present them in the second lesson period. The second lesson was the peer-to-peer observation lesson.

[14] The researcher had tested various adaptations of the instruments in other research projects in the work of the organization

teacher and teacher-teacher trust and comfort levels for a more balanced, critical and interactive discourse. The teachers gradually engaged not only with the researcher challenging questions but more importantly in challenging each other's thinking. Thus, the FGDs shifted gear to reflect elements of teacher co-design discourse in the research processes for improving and changing STEM practice with and through technology, which added to the richness of the findings discussed in chapters four, five and six.

Throughout the field research visits data were collected through field notes and audio recordings. All of the audio data were transcribed by the researcher within one month of completion of each phase of field research. Braun and Clarke (2006) argue that the process of transcribing data orthographically (a verbatim account) 'may seem time-consuming, frustrating, and at times boring' but it can already be considered a key phase in data analysis – an 'interpretative act, where meanings are created, rather than simply a mechanical one of putting spoken sounds on paper' (p17). The processes of data analysis are presented in the following section.

3.6 Data Analysis

As a result of the accumulated collections of notes, lesson artefacts and discourse transcripts, the researcher had a mass of data. Table XV presents an overview of the transcripts and artefacts used in the data analysis.

Table XV - Transcripts and Artefacts

	Transcripts and artefacts	School A	School B	School C	School D
Field Trip 1	Interview 1 – school head	√	√	√	√
	Interview 1 – teacher group	X	√	X	X
	Interview 1 – individual teacher	X	√	X	X
	Focus Group 1 – problem-based lesson	√	√	√	√
	Lesson plans 1 – problem-based lessons	√	√	√	√
	Teacher observation notes 1 – problem-based lessons	√	√	√	√
Field Trip 2	Focus Group 2 – project-based lessons	X	√	X	X
	Lesson plans 2 – project-based lessons	√	√	X	X
	Teacher observation notes 2 – project-based lessons	√	√	X	X
	Questionnaire – lesson teachers	√	√	X	X
Field Trip 3	Interview 2 – school head	√	X	X	X
	Interview 2 – teacher group	√	X	X	X

As can be seen there were twenty-seven different texts analysed and interpreted in total from data collections across the three field visits – eight transcripts from interviews with four head teachers, two teacher groups and one individual teacher[15]; five transcripts from focus group discussions with

[15] One head teacher was interviewed twice on the first and last field trips

teachers from all four schools on the first field trip and two schools on the second trip[16]; seven lesson plans completed by seven lesson teachers and seven sets of lesson observations completed by twenty six teacher observers over the first and second field trips.

Cohen *et al.* (2007) describe the reduction of vast amounts of data as 'one of the most enduring problems of qualitative analysis' (p475). Zhang and Wildemuth (2006) identify content analysis as widely used by researchers for 'data reduction and sense-making… that takes a volume of qualitative material and attempts to identify core consistencies and meanings' (p1). Braun and Clarke (2006) describe thematic analysis as a 'foundational method for qualitative analysis' for eliciting a 'rich and detailed yet complex account of data' that can eschew the 'anything goes' critique of qualitative research (p78). In this regard the researcher opted to conduct a thematic content analysis of the data sets. In all the data analysis took some nine months to prepare and interpret.

The processes involved deductive and inductive ways for what Elo *et al.* (2014, p1) relate as three phases for the 'preparation, organization and reporting of the results' (p1). The deductive analysis involved the preparation of AT and TPACK categorization matrices (Appendices 5.1 and 5.2). The matrices provided a basis for reviewing all of the interview and FGD data for content that could be coded and annotated for emerging themes correspondent with key AT and TPACK concepts discussed earlier. Braun and Clarke (op. cit.) describe deductive top down approaches driven 'by the researcher's theoretical analytical interest' as tending to provide 'less [of] a rich description of the data overall, and more a detailed analysis of some aspect of the data' (p13). After reviewing the emergent themes from the initial analysis and organization it seemed that the data had proved to be indeed very technical, flat and worse – what Halkier (2010) might describe as 'relatively uninteresting' (p86). Somehow the thematic analysis seemed locked into what Braun and Clarke (op. cit.) describe as a 'semantic level' (p30). The themes served to provide clear patterns of the school contexts and teacher practices that could be related to the AT and TPACK conceptual frameworks, but little more. A greater concern was that the AT and TPACK thematic perspectives were somehow not speaking to each other.

The researcher developed three further categorization frameworks to extrapolate a more in-depth 'latent level' of thematic analysis, described by Braun and Clarke (ibid.) as 'starting to identify or examine the underlying ideas, assumptions, and conceptualisations – and ideologies - that are theorised as shaping or informing the semantic content of the data' (p13). The first was a matrix to

[16] The second trip focus group was conducted with teachers from two schools together

align the AT and TPACK codes with ICT-CFT codes linked to the six learning system domains of teacher professional development that underscored the design of the SIPSE intervention[17] (Appendix 5.3). The matrix served as a bridge for supporting two levels of analysis to elicit richer themes: deductive analysis to identify AT-TPACK semantic and latent themes; and inductive analysis to identify broader latent themes from the ICT-CFT professional learning system perspective (Appendix 5.4). The second additional categorization framework was a coding tool adapted from frameworks developed by Koh, Chai, Benjamin and Hong (2015a) to capture the richer and deeper 'interaction' component of the content demonstrating teacher design reflection ideas, turns and knowledge building processes in the FGD discourses (Appendix 5.5). The third additional framework was a coding categorization drawn from the work of Angeli and Valanides (2009), Voogt and Pelgrum (2005) and Harris, Mishra and Koehler (2011) to capture a deeper analysis of teacher lesson observation artefacts related to technology enhanced content representation and pedagogical strategies as perceived and observed by teachers in the lesson activities (Appendix 5.6).

Elo *et al.* (2014) explain that content analysis can be 'as easy or as difficult' (p7) as the researcher allows. The author advocates the use of figures in reporting analysis findings to explain 'the purpose and process of the analysis and structure of concepts' (ibid.). A critical consideration for the researcher given the complexity of the thematic analysis evolution was to make the reporting accessible. The use of figures such as the TPACKtivity Lens (adapted from Terpstra, 2015) mapping how the TPACK, AT and ICT-CFT lenses 'worked' together in the analysis (Appendix 5.7) was a critical tool to convey results in the findings chapters that follow.

Illustrations of the data collection instruments, the data coding matrices, worked examples of the data analysis and examples of the data collected (interview and focus group transcripts, lesson plans and observations) can be accessed in appendices 4, 5 and 6.

[17] Understanding ICT in Education, ICT, Curriculum and Assessment, Pedagogy, Organization & Administration, Pedagogy and Teacher Professional Learning,

3.7 Reflexivity, Reliability and Validity

Sultana (2007) suggests that there is a need to pay greater attention to issues of 'reflexivity, positionality and power relations' more particularly when conducting qualitative research in settings of the Global South where issues of access, equality and relational differences may present fewer barriers 'but may still be problematic' in the way they may 'often precondition exploitation in the research process' (p375). Atkins and Wallace (2012) suggest that in order to achieve a more participative and empowering research approach the researcher needs to acknowledge their 'positionality' – as in considering the way that they may influence the design of the study, the collection and interpretation of data and the relationship with the research participants. Bourke (2014) describes positionality as a space where subjectivism and objectivism meet – where as a researcher 'you have to position yourself somewhere in order to say anything at all' (p3).

In this study the researcher was cognizant of her positionality in terms of her role as simultaneous course designer, researcher, tutor and evaluator in the SIPSE pilot and research interventions. She was aware of the need to pay greater attention to issues of reflexivity and power relations inherent in her multiple roles that could potentially undermine ethical and participatory research commitments and destabilize the tenuous nature of trust in the relationship between the researcher, the head teacher and teacher participant groups throughout the field research. There was a need for close attention to questions of data collection that centred on achieving a more participatory approach that would objectively reflect the voices of the teachers and head teachers participating in the research. The focus was to allow research participants greater powers to steer discussions, to tell their stories and experiences from their perspectives and to create conditions for shared meaning-making and knowledge construction.

On reliability and validity, Noble and Smith (2015) clarify these concepts in qualitative research as related to the 'soundness' of their application (p34). Specifically the authors describe validity in terms of the 'integrity and application of the methods' conducted and 'the precision in which the methods accurately reflect the data'. They describe 'reliability' in terms of 'consistency within the employed analytical procedures' (ibid.). Bryman (2012) points out requirements to find alternative ways to assess the quality and 'trustworthiness' of qualitative research given the historical association of reliability and validity with quantitative research concerns for the measure of things (p390). Noble and Smith (2015) point to Lincoln and Guba's (1985, cited in ibid.) criteria for 'truth value, consistency, neutrality and applicability' as a means and an alternative framework for demonstrating rigour within qualitative research.

Key procedures to ensure the reliability and consistency of the analysis and findings in the research inquiry integrated the DBR Collective (2003) guidelines for ‘triangulation of data collection from multiple data sources’ (as in head teachers and teachers across the four research school sites), the ‘repetition of analyses across cycles of enactment’ (as in analysis of data collections from different phases of the *knowledge deepening* cycle) and the ‘use (or creation) of standardized measures or instruments’ (p7) (as in the use and adaptation of AT, TPACK and ICT-CFT tools drawn from the literature and tested for reliability and validity) (p7).

In terms of ensuring the validity of the research findings several procedures were undertaken. First was the use of several layers of data analysis involving three conceptual lenses, deductive and inductive methods, repetition of analysis across different cycles of the intervention, to try to ‘accurately represent the information that the participants provided’ and ‘to reflect the participants’ voice and conditions in the inquiry’ (Elo *et al*., 2014, p6). Second was a procedure inherent in the DBR approach of partnership building between the researcher and teachers for ‘understanding’ (and as such validating) (Cohen *et al.*, 2007, p135) the alignment and application of the ‘theory, design, practice and measurement over time’ (The DBR Collective, 2003, p7) of the teacher’s professional learning through different iterations of the SIPSE intervention. Third was a procedure to ensure confidence in the results that involved the selection of data for analysis and findings discussion that was representative of all data sets (op. cit.), that addressed the constructs (theories and explanations) of all participants (head teachers and teachers) and that captured the ‘keyness’ (importance) as well as ‘prevalence’ of themes (Braun and Clarke, 2006) emerging from the data sets to address the research questions (Appendix 5.8). A final procedure was the process of continuous review of the research drafts with the research supervisor. Given the researcher’s ‘dual intellectual roles of advocate and critic’ (The DBR Collective, 2003, p7) of the SIPSE intervention, the supervisor provided a critical external support and perspective to assist the researcher ‘question [her] tacitly held assumptions’ and to meticulously document ‘processes of enactment to establish warrants for claims’ (ibid.) on the intervention impact and knowledge generation.

3.7 Chapter Summary

This chapter identified clear research questions aimed at appraising the SIPSE teacher professional development intervention for STEM teacher ICT use in classroom practice in Kenya. The research strategy, qualitative research paradigm, and research-based design methodology which underpin the study were discussed. The data collection instruments were described in relation to their alignment with research questions and their application in the field research. The thematic content analysis approach was explained as well as the iterative processes to refine analysis instruments for a more rigorous and deeper interpretation. The issues of ethical considerations, positionality, validity and reliability were addressed to clarify the steps taken to ensure the creditability and trustworthiness of the inquiry. In the following three chapters a discussion and analysis of the findings will be presented.

CHAPTER 4

The Object of ICT in Teaching and Learning

4.0 Introduction

The following three chapters will present an analysis and interpretation of the qualitative data sets gathered during this study. The data sets are linked to the key aim of the research which was to critically appraise the innovation model in relation to teacher development for ICT use in classroom practice associated with the Strengthening Innovation and Practice in Secondary Education (SIPSE) programme over the two cycles of its pilot phase implementation. The appraisal of the programme was examined from the three perspectives presented in the research questions related to: 1) the object of ICT integration perceived by teachers and head teachers throughout the SIPSE intervention cycles; 2) the characteristics of teacher design for ICT use in STEM teaching and learning mid-way through the programme, as evidenced in their approach to problem-based activities; 3) and the characteristics of teacher design for ICT use in STEM teaching and learning at the end of the programme, as evidenced in their approach to project-based activities. There were three main themes that emerged from the data findings, namely: the object of ICT integration in teaching and learning; teacher technology content knowledge and ICT use in problem-based activities; teacher technology pedagogy knowledge and ICT use in project-based activities.

This chapter will consider the first theme 'the object of ICT integration in teaching and learning' and its correspondent **Research Question 1: 'What is the object of ICT integration in teaching and learning perceived by head teachers and teachers during the two cycles of the SIPSE model intervention?'**

In this theme, participant narratives linked to Activity Theory (AT) *Object of ICT Integration* and Technology Pedagogy and Content Knowledge (TPACK) *ICT-Technology Knowledge (ICT-TK)* sub-themes predominated. The criterion for selecting the issues to be considered from among the participant narratives, was based on how these were linked to the *Understanding ICT in Education (Policy)* system domain of the ICT Competency Framework for Teachers (ICT-CFT) which underpinned the SIPSE programme design. The TPACKtivity lens was used to focus on the evolving nature of the 'conceptual and practical tools' (Terpstra, 2015, p68) that participants utilized to express their ideas and beliefs about the object of ICT integration as they moved through the SIPSE programme of *technology literacy* and *knowledge deepening* cycles.

4.1 The Cultural-Historical Context - Educational Visions and Problem Spaces

Two key issues were illuminated from the findings in this theme. First how competing national agendas of education vision and policy created contradictions in participant views and perceptions on the object of teaching and learning in schools. Second how these perceptual contradictions created further dissonances in participant ideas about the object of ICT use in teaching and learning in the schools.

Starting with the object of teaching and learning, while each school setting had their own specific teaching and learning contexts, head teacher and teacher perspectives were influenced by the broader and more complex settings of the public education system in Kenya. The head teacher discussions across the schools illuminated a critical narrative on the issue of balancing multiple and often competing national policy requirements in daily school practices. For example, one head teacher described the pursuit of academic excellence as the underpinning philosophy of the school – while the school also tried to nurture their student life skills to adapt and value local skills and knowledge:

> The school is mainly a centre of excellence in pursuit of educational excellence…, the main area of competition is on academic excellence…, but we try to inculcate virtues within the students so that they perform very well in all areas, so that they inculcate values for life skills, they go to the farm to pick the vegetables, they clean dormitories, so that they can survive in the environment.
>
> Head Teacher 2, Interview, School B, September 2014

The apparent dissonance in school weighting of academic performance over life skills as *"the main area of competition"* was reflected in other themes in the object of teaching and learning discourse. For example, some head teachers commented on educational paradigmatic shifts towards the centrality of the learner. These were described by one head as shifts in national and school policy visions that seek to encourage 'learner friendly' school environments:

> In the child friendly school system the students are going to embrace whatever is going on in the school. And they look on it as something for their own good, I [the student] am not just being pushed. [This is] not a situation that I [the school] forced you to learn because that is on the syllabus. So you [the learner] can feel that, it's not a punishment to embrace some of these things. It is more of getting into a passion for learning that in the long run will be for my own benefit [the learner's own benefit].
>
> Head Teacher 4, Interview, School D, September 2014

The head teacher expressions of *"passion"* and *"punishment"* associated with school learning presented apparent contradictions related to the purpose of teaching and learning in the schools. They are contradictions reflected in national policy frameworks describing sometimes contending goals for determining the shape and quality of education delivery in the Kenyan school system. The Kenyan Basic Education Act (2013) outlines national education objectives and policies for education access, quality and equity that may be understood as inherent in the head teacher talk of academic excellence. On the other hand the Kenya Institute of Education (KIE)[18] 'Life Skills' programme (2008) with its agenda for education to move beyond the 'prioritization of academic knowledge' to prepare young people 'to develop positive values, attitudes, skills and healthy behaviour in order to help them effectively deal with the challenges of everyday life' (p3) would appear at odds with the schools' competitive agenda for 'academic' excellence. The 'Child Friendly School' philosophy to ensure a child's holistic development 'to equip them with the skills to face the challenges of a new century'(UNICEF, 2011) represents one of a growing field of international frameworks that have been contextualized and adopted into national policy guidelines vying for school attention.

The complexity of competing goals is further illuminated in a dimension of 'equity' policies that emerged in head teacher narratives. In this regard McDonough and Le Baron (2010) suggest that equity can be viewed from a variety of perspectives related to personal identity inclusive of gender, special needs and socio-economic status. The following head teacher reflections described some of the dilemmas and conflicts in engaging with multiple policy ideologies for promoting girl child education, for ensuring free educational access to those in need, and for fostering inclusion of students marginalized by the breakdown of family life and values in modern Kenyan society:

> The school is focused, actually our school mission is to capture…, to bring out the full girl child's potential. So in our strategic plan our biggest interest is to nurture the girl child and to ensure that we bring out her full potential.
>
> Head Teacher 3, Interview, School C, September 2014

> Because there has been a lot of emphasis on the girl child in Kenya, it looks like we are losing out on the boys…, because now the biggest challenge for the boys' schools in Kenya is the issue of drug abuse…, we have invited speakers to warn of the dangers…, we have talked to the parents…, we invited national bodies [on drug abuse] …, so we keep on advising our students on issues of drugs.
>
> Head Teacher 1, Interview, School A, September 2014

> We find parents who cannot afford to pay the fees [for boarding] or they struggle. The good thing is we had some support from the ministry… , we have had some partnerships with the banks in terms of paying fees for the students… There is a challenge of some students who come from single parents…, they have issues from home…, like learning about discipline, issues from students who don't have a father, they have single mothers. There are very many of them with discipline issues for some reason or another.
>
> Head Teacher 4, Interview, School D, September 2014

However, the data illuminated a contradictory force that would seem to be pushing the schools towards more pragmatic than idealistic resolutions of policy dilemmas.

> The big focus is just in terms in performance…, implementing the ministry curriculum. The focus is to try as much as possible to get the best grades possible and to try and push the number of students to getting to tertiary institutions after their fourth form.
>
> Head Teacher 4, Interview, School D, September 2014

---

[18] Kenya Institute of Education (KIE) established in 1968 was succeeded in 2013 by the Kenya Institute of Curriculum Development (KICD)

> We launched our first strategic plan and we had set our targets in every year…, our focus was to increase our average mini-grade[19] in KCSE[20] by 0.5 every year. We also looked at our curriculum and analysed the subjects that perform very well. And we made them compulsory for the entire school. I have a case in mind of C.R.E[21] that is compulsory for the whole school.
>
> Head Teacher 3, Interview, School C, September 2014

From a TPACKtivity lens the *"push"* and *"compulsory"* language in the head teacher pragmatic expressions represents another dimension of the discourse. They constitute a 'mediating conceptual tool' to explicate pragmatism as a critical driving force underpinning teaching and learning processes in the schools. It is a conceptual understanding that is aligned with Ang'ondi's (2013) explanation of Kenyan secondary school cultures where almost everything that is done 'must have an examinable implication' (p26). It is a cultural pragmatic perspective that would seem to cut to the core of broader ideals and values of education policies and philosophies as reflected by Head Teacher 2 in this end-of-project interview reflection:

> Yeah – at the level where I am we can now look at education and say, is it really meeting the needs of Kenyans, right, is it, that is the question, after a child has finished a stage, is it really meeting the needs, the objectives of that particular stage? And to be honest with you it is not… we are producing children, who feel, eh, you heard of cheating in exams in Kenya, why do people cheat in exams in Kenya…,because it is the only tool to say that you are good or bad…
>
> We do not have any other tool, right… It means our system does not instil values, to the children, right, so, values are not instilled, there is a life skill lesson in school, ok, where we talk about attitude, about many things, many nice things by the way, but nobody takes it seriously because it is not examinable…, we need to overhaul our system.
>
> Head Teacher 2, School B, End of Project Interview, February, 2016

The head teacher disillusion and pragmatism in the face of educational learning and assessment challenges is not a new dilemma. It is reflected in national debates on the restoration of credibility and dignity values in an examination system that has been bedevilled by escalating cheating scandals (Daily Nation, 6 March, 2016).[22] It is reflected in the chapter two literature on education system challenges to integrate relevant learner competencies integral to educational reform projects – whether competencies emerging in the 21st century skills literature (Voogt & Roblin, 2010, 2012; Akyeampong, 2016) or those emerging in the Kenya learner friendly school cultures.

[19] A 'mini-grade' is equivalent to a school's 'mean score' which indicates its ranking in national league tables of examination results

[20] KCSE - Kenya Certificate of Secondary Education

[21] CRE – Christian Religious Education

[22] The cancellation in 2015 of KCSE exam results for some 5,100 candidates accused of cheating [was] the highest in the history of the national examination (ibid.)

The teacher commentary on teaching and learning presented other permeations in the educational vision and problem space reflections. For example, the following lesson teacher interview and questionnaire responses on their beliefs and objectives in teaching and learning would seem to present a contrast in tone from the ‘push’ and ‘compulsory’ undercurrents in the head teacher discourse.

> Well I’ve been teaching with the students…, and it needs to be interactive
>
> Lesson Teacher, Science, Interview, School C, September 2014

> To make the teaching/learning more interesting make the concepts more real and less abstract.
>
> Lesson Teacher, English, School B, Questionnaire, February 2015

> My main objective is to make mathematics more interesting to the learners and also engage the learners more actively involving them in the learning activities
>
> Lesson Teacher, Mathematics, School A, Questionnaire, February 2015

> To provide variety in teaching and learning for better comprehension and retention of concepts by the learner and therefore better results.
>
> Lesson Teacher, Mathematics, School B, Questionnaire, February 2015

The teacher perceptions and beliefs would appear to have commonalities with the head teacher discourse of student learning for better comprehension and retention of school ‘academic’ knowledge for better results. Yet there is an underlying emphasis in their commentary of making teaching and learning processes more *“interactive”, “interesting”, “diverse”* and *“involving”* of the learner that has more in keeping with the learner centred ideal philosophy of national and school policy frameworks. It would seem to introduce a teacher ‘pull’ and ‘engaging’ contrast in the teaching and learning discourse. Yet the ‘learner centeredness’ of the teacher commentary points to a potential ‘teacher’ vacuum in the discourse - an aspect that was alluded to by School B Teacher 2 in the following end-of-project interview reflection:

> One of the things that [SIPSE] has really assisted me in doing is understanding my learners better, that for me is very important, understanding my learners better. Any lesson I prepare, I have the learner in mind, so I make sure I customize my learning lesson to fit my learner, to make sure I get the best out of, out of my learners, ah, initially I would teach, and then I would assume that all is well, I used to think that the way I was teaching used to be the best, I thought it was, I would get results, so I used to think it was the best.
>
> Teacher 1, Mathematics, End of Project Interview, School B, February 2016

Like the inadvertent tensions surrounding girl and boy child policies presented earlier, the teacher’s comments may contain an unexpected contradiction in their emphasis on the ‘learner’ and ‘learning’ that would seem to undermine their former ‘teacher’ and ‘teaching’ good practice identity. It is a language of conceptual polarity that is reflected in national and international policy and discourse centred on the quality of the ‘learner’ and ‘learning’ experience with less attention ‘on the role of *teachers* and *teaching* which are key to the provision of good quality education’ (EFA GMR Team, 2015, p1).

Following on from the object of teaching and learning, were questions on what participants saw as the object of ICT use in teaching and learning. A key narrative in the data sets was the potential of ICT to 'fit' with the change paradigms integral to national policy frameworks 'for using modern technology to enhance access and promote quality in education' (Ang'ondi, 2013). In the following narratives, for example, the head teacher comments centre on ICT potential for promoting learner friendly interactive environments integral to national reform frameworks discussed in the previous section.

> The ICT [school] policy is related to the Ministry of Education policy on learner centred teaching methods. So when they encourage learner centred, [approaches] we embrace ICT in our teaching and learning. The learners are actively involved in the learning process. Because when the teacher projects the content, the learners are able to identify maybe some of the things that are projected there.
>
> Head Teacher 3, School C, Interview, September 2014

> The whole idea is to make those students and the teachers embrace the use of ICT, because that's the way to go… And the teachers have actually embraced the project…, they are actually teaching by getting lessons online, going to the class with the projectors and laptops…, and it's made our learning friendlier, and we are seeing the big change in terms of interest in some of the subjects.
>
> Head Teacher 4, School D, Interview, September 2014

The head teacher commentary for *"embracing"* the technology tool presented a feature in the discourse that would seem to suggest affordance in the technology tool itself for creating change. This understanding would appear to have shifted the 'centrality of the learner' a notch to include a 'centrality of the technology tool'. For example, the following head teacher narrative would appear to objectify new technology tool affordances within broader frameworks for creating paradigmatic shifts from traditional practices towards the use of ICT as the tool for curriculum delivery.

> When it comes to the curriculum, you have the traditional way of delivery, what we call it chalk and talk. But we are trying to move or shift our way of delivering towards the ICT, so, our focus now is towards ICT and how we can use it to, to deliver the curriculum…so the emphasis now other than just the traditional way of teaching, is the shifting towards the ICT, technology.
>
> Head Teacher 1, School A, Interview, September 2014

There is a resonance in the literature with the 'shift' towards technology as a 'mediating artefact' that has the potential 'to mediate learning and to shape the ways in which learning can occur' (Zevenbergen & Lerman, 2007, p859). However, there is a dissonance in this discourse related to the assumption of educational change and learning innovation as integral to the technology tool. The contradiction was illuminated in two contrasting dimensions of the following narratives. First head teacher narratives for ICT strategies appear weighted in the centrality of the learner and technology discourse for shaping change. The teacher's role in the narratives remains located in the traditional paradigm of subject knowledge delivery albeit in an ubiquitous mode inside and outside of the classroom.

> We have in the strategic plan for the next 5 years, we are putting up a computer centre where most of our students can fit in – so that by the time the 5 year plan will be over, there will be a bigger room to accommodate more students.
>
> Head Teacher 2, Interview, School B, September 2014

> We do have a direction that we would like to take as a school, one we would like to look at in the next 5 - within 5 and 7 years, we would like to see whether the students are able to have their own gadgets, and the teacher delivers the subject content not just in class, but even after class, the students are to have [access], they are able to engage.
>
> Head Teacher 1, Interview, School A, September 2014

Second in the following teacher narrative their ideas about using ICT in their practice reflect the head teacher views in weighting the centrality of technology as a powerful tool for more effective learning and in the final instance for more effective teaching.

> Also ah, technology is very useful because the learners can ah, can review the lesson at eh, their own time, compared to the other methods of teaching, remember you teach them from the blackboard, and the only point of reference it is their notes, but eh I think the lesson can be reviewed at any time they want, so I think that technology is a little bit better.
>
> For example my students now are preparing for exams, like I'm teaching Maths, and the candidates when they are waiting for the exams, those are the lessons I am giving them, and they follow when I am not there, the students are able to open the laptop, they assess the lesson [on teacher prepared presentations] and they compare it, and it is a way, a very good way of teaching.
>
> Teacher 5, Focus Group Discussion, September, School C, 2014

The dissonance lies in the teacher's conceptual framing of new technology use as a *"very good way of teaching"* that had much in common with the head teacher scenario of teaching situated in the traditional paradigm of teacher lesson delivery. The symbolic replacement of the traditional *"blackboard"* and *"notes"* technologies with the ubiquitous affordances of new technology to better prepare students for external examinations would further seem embedded in the 'push' and 'pull' competitive culture of schooling discussed earlier. It would illuminate further a conceptual vacuum on what is the changing role of the teacher and what constitutes 'a very good way of teaching' in education shifts towards technology and learner centred paradigms.

It is a vacuum also reflected in the literature where McDonough and Le Baron (2009) critique applications of technology implementation in conventional school practices as having undermined its potentially transformational properties (p7). From a TPACK perspective Angeli and Valanides (2009) contend that the technology in itself and of itself is not a transformative mechanism but rather it is what people do with the technology that makes a difference. From an AT perspective Hardman (2005) suggests a reciprocity in tool mediation where teachers and students can change the technology tool 'and be transformed by it over time' (p259). Yet the transformative view of ICT use for influencing change in teaching processes as pre-requisite to change in learning processes seemed elusive in head teacher and teacher discourses.

In summary, this section has highlighted evidence of opportunities and tensions in head teacher and teacher narratives on the object of teaching and learning in schools associated with competing national agendas of education vision and policy. The evidence was articulated in school practice competing agendas for academic excellence and examination success and 'Life Skills' programmes for developing student values, attitudes, skills and behaviours to deal with challenges, changes and opportunities of daily life in Kenya society. Notwithstanding the tensions, there was some evidence of an underlying theme in participant commentary of making teaching and learning processes more interesting, interactive, inclusive and involving of the learner in keeping with the learner-centred philosophy of some national and school policy frameworks.

On the object of ICT in teaching and learning, head teacher and teacher narratives highlighted beliefs in the affordances of technology to advance national policy agendas for inclusive and learning friendly classroom and school environments. The emphasis on learners, learning and investment in ICT appeared to position technology as a powerful tool mediation in itself for more effective learning. There was dissonance in the participant narrative reflections that highlighted an apparent vacuum in defining the teacher's role and what constitutes 'good teaching' in the 'push' and 'pull' of educational currents towards technology and learner-centred paradigms. It is a conceptual gap in the discourse and the literature that will be explored at a deeper level in the following sections of the theme.

4.2 Teacher Technology Knowledge – Changing Technology, Changing Practice?

Teacher's technology knowledge (TK) relates to their abilities to use and master a variety of digital technologies and to create digital artefacts to accomplish tasks in their classroom practices (Ouyang, 2015). In this theme teachers TK integrates an ICT strand (ICT-TK) (Angeli & Valanides, 2009) to take into account their perceptions and beliefs about ICT affordances that can influence their decision making on TK application in classroom practice.

The data in this theme revealed three key findings. There was evidence of teacher technology knowledge application that was centred on less sophisticated tool use to support existing practices.

The object of teacher tool use was influenced by their conceptual and practical frames of tool affordances for fast tracking student understanding in school examination oriented cultures. The third finding revealed an unexpected narrative of teachers' more sophisticated aspirations for tool use to change practice.

The first key finding on teacher technology usage to support existing practice was evident in a mapping of teacher intended usage of new and traditional technologies. The mapping is based on their lesson plan preparations for the four problem-based lessons (three Science and one English) and three project-based lessons (two Mathematics and one English) conducted during the first and second field research visits (Table XVI).

Table XVI - Lessons, Resources, Teachers and Teacher Observers

Schools	Lessons	Resources		Teachers	
		ICT resources	**Non-ICT Resources**	**Lesson Teacher LT**	**Teacher Observers – TO**
Problem-based Learning					
School A	**Biology Topic** The Function of a Nephron	MS PowerPoint Presentation with embedded video clip simulation of nephron function	Not mentioned	LT -Biology	TO 1: Mathematics TO 2: ICT TO 3: English, TO 4: Physics/ Mathematics TO 5: Chemistry
School B	**Biology Topic** Photosynthesis: Light and Dark Reaction	MS PowerPoint Presentation with embedded video clips of photosynthesis processes, Student handouts	Blackboard, Reference materials, writing materials, pen and pencil, markers, manila paper	LT Biology	TO 1: English TO 2: Mathematics, TO 3: ICT TO 4: Physics TO 5: Chemistry
School C	**Biology Topic** The Role of Hormones in Insect Metamorphosis	MS PowerPoint Presentation with digital pictures/ images	Not mentioned	LT - Biology/ Chemistry	TO 1: English/ Literature TO 2: ICT T3: Chemistry T4: Maths/ Physics, T5: Physics
School D	**English Topic** Sentence Structure, Paragraph Writing, Debate	MS PowerPoint Presentation with embedded video clips; Video clips of students performing a small skit (digital story); Student handouts	Whiteboard, writing materials, pen and pencil	LT - English	TO 1: English/ Literature TO 2: Mathematics/ Physics TO 3: Biology 4: Physics SD-TO 5: Chemistry
Project-based Learning					
School A	**Mathematics Topic** –Loci	Webquest PowerPoint Presentation, Internet, Computer Lab, GeoGebra software	Blackboard, reference materials, geometrical set, writing materials, graph paper, pen and pencil, markers, manila paper	SA-LT Mathematics	SA-TO 1: English, SA-TO 2: Physics/ Mathematics, SA-TO 3: Chemistry, SA-TO 4: Biology

Schools	Lessons	Resources		Teachers	
		ICT resources	Non-ICT Resources	Lesson Teacher LT	Teacher Observers – TO
School B	**Mathematics Topic**- Trigonometric Graphs – Determining wave parameters	Webquest PowerPoint Presentation, GeoGebra software, Internet	Blackboard, reference materials, geometrical set, writing materials, graph paper, pen and pencil, markers, manila paper	SB-LT Mathematics	SA-TO 3: Chemistry SA-TO 4: Biology SA-LT: Mathematics
	English Topic - Report writing – Health Hazards in Our School	Webquest PowerPoint Presentation; Computer lab; Word processing & PowerPoint skills tutorials	writing materials, pen and pencil,	SB-LT English	SA-TO1: English
Source: Teacher STEM Lesson Plans – Problem-Based and Project-Based Learning					

The lesson plan mapping illustrates design features of intended technology usage by the teachers that was mostly dominated by the presentation software tool - with novel tools here and there for 'webquest' presentation (associated with project activities) and 'GeoGebra' and 'concept mapping' tools (associated with problem-solving activities). The teacher commentary in FGDs and lesson observation notes confirmed a distinct preference for presentation software as the 'practical mediating tool' (Terpstra, 2005, p68) in lesson design. The following extracts highlight the multiple ways that teachers mastered and used presentation as an organizational tool to achieve lesson objectives, present key concepts, link to other multimedia formats of You Tube video, simulations and teacher-produced video story, and to integrate traditional technology resources of textbooks, manila paper and student worksheets from problem- to project-based lessons.

> The technology that I applied was the PowerPoint using simulations and videos, and the students appeared to, to understand what was happening…
>
> Lesson Teacher, Science Problem-based Learning Lesson, School A, Focus Group Discussion, September 2014

> Presentation - PowerPoint…, the technology is infused with the use of images of insects from the internet
>
> Teacher Observer 1, Science Problem-based Learning Lesson, Peer-to-peer lesson observation notes, School C, September 2014

> I felt that ah – everything was well used, the technology that is the video clips, the content from the textbook was well placed and the learning objective was, was eh fulfilled.
>
> Lesson Teacher, English Problem-based Learning Lesson, Focus Group Discussion, School D, September, 2014

> The ICT resources used was a PowerPoint Presentation alongside non-ICT resources like Manila papers.
>
> Lesson Teacher 1, Mathematics Project-based Learning Lesson, Peer-to-peer lesson observation notes, School A, February 2015

Use of slides and worksheets enhanced the lesson presentation.

Teacher Observer 3, Mathematics Project-based Lesson, Peer-to-peer lesson observation notes, School A, February 2015

A particular affordance commented on by most of the teachers was the novelty of new technology to motivate and engage the learners. In the following narratives the teachers articulated the contrast between the conceptual and practical affordances of traditional 'teacher talk' and 'blackboard' tool mediations with the more exciting new technology tool mediations for student *"reduced boredom", "alertness", "interest", "claps", "understanding"* and *"internalization"*.

> These tools reduce boredom as the students were alert as well as making it easy to link the video content to the topic
>
> Teacher Observer 3, English Problem-based Learning Lesson, Peer-to-peer lesson observation notes, School D, September 2014

> I saw the students were very interested in the images eh, which showed the kind of stages [metamorphosis] the teacher was giving - moving from stage A to B, and stage B to C, they were quite interested, because it is the kind of thing they are seeing in the day to day activity.
>
> Teacher Observer 2, Science Problem-based Learning Lesson, Focus Group Discussion, School C, September, 2014

> I think they [the students] understood the process better [with the presentation tool]…, than the actual work that they are used to here, talking, just talking and writing a few things on the blackboard – so there was a good link between those two, we don't get claps every other time after a lesson do we (laughter)…, so when the students clap you're feeling you have taught a successful lesson, so the content was very good and it was internalized by the learners
>
> Teacher Observer 1, Science Problem-based Learning Lesson, Focus Group Discussion, School B, September, 2014

The teacher preference, usage and mastery of presentation technology could also reflect key elements of what Harris (2008) describes in the literature as the 'content, structure and advantage' (p253) of the new technology tool. In this regard the following Teacher 2's commentary underlines perceived presentation advantages for easing the work of the teacher, for structuring lesson unit design that speeds up the topic delivery, and enables learner access to more engagement with content.

> Now using the technology, using this kind of technology,… the teacher gets more, the learner gets more, the teacher work becomes easier…, a topic that I would take around 10 lessons to teach, I can now do it in 6 lessons, because I can spend 1 or 2 lessons illustrating about the topic, using different modes, I can use a clip a video clip and for me I like PowerPoint presentations more than the clips, because with eh PowerPoint presentations there is that aspect of continuity
>
> Teacher 2, Mathematics, End of Project Interview, School B, February 2016

However, Teacher 2's conceptual framing of "*the teacher gets more, the learner gets more*" was contradicted in other teacher narratives that alluded to a disequilibrium between teacher *"didactic"* and *"explanation"* and student *"listening"* and *"observation"* roles in the teacher employment of presentation.

> The teacher used ICT to project the lesson content and activities - the students made observations and the lesson progressed.
>
> Teacher Observer 2, English Problem-based Learning Lesson, School D, Focus Group Discussion, September 2014

> Students were only listening to video clips and also viewing the slides. From the video clips and slides students were able to answer the questions.
>
> Teacher Observer 4, English Problem-based Learning Lesson, School D, Focus Group Discussion, September 2014

> The teacher used the didactic, didactic teaching…, because there was quite a bit of explanation as to what was on-going in the presentation.
>
> Teacher Observer 1, Science Problem-based Learning Lesson, School A, Focus Group Discussion, September, 2014

> The students em [pause], appeared to understand what was happening [pause], and they didn't analyse…
>
> Teacher Observer 2, Science Problem-based Learning Lesson, School A, Focus Group Discussion, September 2014

There is dissonance in Teacher Observer 2's observation on the lack of student analysis. This observation though not representative is significant in identifying a critical limitation in the teacher use of the presentation tool to support the dynamics of student engagement at a conceptual and practical level – in relation to concept analysis and engagement with technology central to module themes of the knowledge deepening cycle. For example, the following teacher narratives present somewhat contradictory views of appreciation of teacher mastery of presentation and simulation combined artefacts to support the *"learning being done"* and limitations in student access and interactive engagement both with the new technology tools and the traditional tools they replaced.

> The choice of technology (simulation and PowerPoint Presentation) is excellent and suits the learning being done… Concept mapping may still be applied to allow more critique and brainstorming amongst students.
>
> Teacher Observer 5, Science Problem-based Learning Lesson, School B, Focus Group Discussion, September 2014

> Technology used [in the lesson plan] was GeoGebra software; students [in the assignment work] mostly derived their concepts from non-ICT resources [geometric sets]
>
> Lesson Teacher 3, Mathematics Project-based Learning Lesson, Peer-to-peer lesson observation notes, School B, February 2015

> Students should have demonstrated the use of compass.
>
> Teacher Observer 1, Mathematics Project-based Learning lesson, Teacher observer notes, School A, February 2015

The teacher narratives in project lesson FGDs presented similar tensions and challenges regarding the locus of technology control. The lessons were designed by the teachers to be carried out over two classroom periods to provide scope for student engagement in the 'webquest' project processes and tools. However, the following teacher views intimated a teacher conceptual frame to push student engagement with technology tools *"outside"* the classroom, as something peripheral to rather than integral to classroom activities:

> And eh… they [the students] went out [after the first lesson]… ah fortunately I think they weren't inexperienced as far as technology was concerned. They were able to access the website, resources that were, that they were directed to…
>
> Lesson Teacher, Mathematics Project-based Learning Lesson, School A, Focus Group Discussion, February, 2015

> From the way they [students] were presenting, it appeared that they had thoroughly researched what they had presented. In fact because they had the first lesson yesterday and then the second lesson today… I think they had enough time to research… however I noted there was no use of eh… the ICT technology…, they were using non-ICT, because they were using the manila papers, the pointers, the chalkboard, and so on… the students were not able to use the laptop and the projector during presentation
>
> Teacher observer 4, Mathematics Project-based Learning Lesson, School B, Focus Group Discussion, February, 2015

> Going forward we can only improve on this and even the mode of presentation. At some point I am imagining our students will be able to interact directly with the technology themselves… rather than the teacher just ah… monopolizing the presentation
>
> Lesson Teacher 1, English Project-based Learning Lesson, School B, Focus Group Discussion, February 2015

The teacher patterns of tool usage were not dissimilar to patterns reported in the literature which suggest that most teachers struggle to integrate high quality digital learning tools (Boschmar *et al.*, 2016) and turn to more accessible technology tools such as presentation software and the internet to support and enhance their existing practices (Trucano, 2005; Harris, 2008). Yet the teacher's reflections on *"going forward"* from current teacher *"monopolization"* to student *"direct interaction"* with technology seemed to present teacher aspirations of moving from teacher-directed to student-directed technology enhanced classroom scenarios.

The second key finding centred on teacher shifting conceptual frames on new technology potentials to support or change existing practices. The following teacher narratives at the end of the knowledge deepening cycle revealed divergent teacher perspectives on new technology tool affordance for change or continuation of current practices.

> Use of slides and worksheets enhanced the lesson presentation. Technology shaped the students thinking and students quickly understood the concepts to be learned.
>
> Teacher Observer 3, Mathematics Project-based Learning Lesson, Peer-to-peer lesson observation notes, School A, February 2015

> Even in the assignment that you give after the lesson, after the ICT based lesson, the PowerPoint, you give an assignment… it's a big difference, between the way that they will do that assignment, how they would score, and the way that they used to before we used that method … that's results, so if the results are in the lesson, in the assignment, that is bound to show, to reflect in the end result, in KCSE[23]
>
> Teacher 1, English, End of Project Interview, School B, February 2016

The first teacher observations of technology *"shaping"* learner thinking and understanding suggests teacher conceptual frames of tool affordances for facilitating more profound learner development processes akin to 'dialectical thinking' processes discussed by Engeström *et al.* (2014) as associated with 'the principle of ascending from the abstract to the concrete' (p6). Conversely the second teacher reflections on the "*big difference*" of technology use in enhancing student performance suggests teacher conceptual frames of tool efficiencies for fast tracking understanding akin to what Engeström *et al.* (ibid) described as 'abstract-empirical generalizing' common to the 'daily routines, work instructions, production design' that dominate 'many professional and organizational structures' (p7).

The dialectical tensions between the two perspectives were captured in Head Teacher 2 end-of-project interview reflections on technology use in the daily practices of the school organization that would appear to lock the *"work of the teacher"* into dominant design frames for learner *"conceptualization and reproduction"* determined by the school examination *"end product"*.

> I am very happy because we are thinking about an overhaul of our curriculum and an overhaul of our education system, and we have put it very clear to them that we need a system that is not exam oriented.., and eh, so the teacher would like to finish the work, are you getting, to finish the work…, we are pressed to complete the syllabus, the exam will come from here to here, and we seem to just be rushing, we are just rushing, so sometimes, em, ok, to be honest it [PowerPoint] helps, especially on concepts, it helps like I said earlier to make the concepts clear…, and you see our end product is the exam, you see, will the child be able to conceptualize this and reproduce in the exam.
>
> Head Techer 2, School B, End of Project Interview, February 2016

From a TPACKtivity perspective the introduction of new technology into the work practices of the school organization would appear to have surfaced dilemmas that limited the scope of teacher usage of new technology tool affordances in the 'knowledge deepening' cycle. The data would suggest teacher application of technology knowledge to have remained at a 'technology literacy' level for improving existing practice. In the literature Butler *et al.* (2013) report the technology literacy level to be a common feature of ICT use in most school cultures. Engeström (2001, 2014) explains the dilemmas of technology introduction in schools as creating a 'double bind' situation placing

[23] KCSE - Kenya Certificate for Secondary Education.

contradictory demands on teachers and schools. Mishra and Koehler (2008) point out such dilemmas as the ‘wicked problem’ of technology integration for which there is no definitive solution.

Yet the third key finding highlighted an unexpected teacher narrative of more sophisticated aspirations for tool use. It was linked to the literature discussions in chapter two on teachers’ ‘design thinking’ capacity (Koh *et al.,* 2015a). The observation and FGD data across the schools illuminated critical emergent trends in teacher design thinking to resolve tensions and contradictions illuminated in this theme.

Table XVII shows a teacher collaborative design thinking process that was mapped by the researcher from an FGD conducted in Research School D. The mapping uses a framework tool adapted from the work of Koh *et al.* (ibid.) to show design and knowledge building processes in teacher post-lesson observation ‘talk back’ (p88) which helps them to frame and reframe their understanding of problems and to work out solutions. The interchanges between the teachers and the researcher (lines 1–7) show a series of what Koh *et al*. (ibid.) describe as ‘design-turns’ (p95). In each turn the teachers analysed the problems in current practice such as Teacher Observer 1’s analysis of the lack of time that is a problem constant in the daily routines of the teachers (lines 1a–d) and Teacher Observer 3’s comment on the lack of student access to online information sources in the classroom (line 5a). Each analysis lead to a tentative conceptualization of new ideas to resolve the tensions. For example the Lesson Teacher’s design frame for exploring teaching and learning synergies within and beyond the classroom (lines 3a-i), Teacher Observer 3’s clarification of new practice potential for interchangeable usage of classroom and lab facilities (lines 5b–c) and Teacher Observer 5’s ideas about the use of student mobile phone devices (lines 8a–d) to enable access and extend the teaching and learning engagement.

The teacher design ideas appear to be both elementary and radical. On the one hand there is nothing extraordinary about teacher usage of the computer lab or mobile devices as an extension of classroom activities. On the other hand from a TPACKtivity perspective it would present a radical new design frame for teachers working in school contexts where the computer lab has ‘cultural-historical’ (Terpstra, 2015, p63) associations of fixed access for students taking ICT as a specialist subject as hinted in Teacher Observer 1’s commentary (lines 7a-d) and where student mobile devices as suggested in Teacher Observer 5’s commentary (lines 8a–d) are banned from school premises.

Table XVII - Seeding New Design Frames for Student Access

Focus Group Discussion Transcript	Design Process	Knowledge Process
1. Teacher observer 1		
a) I am talking about first the time that we have	Analysis – describe current practice	PCK
b) Because each and every time we are talking about the time constraints, it will be a national anthem c) I mean it will not change. d) The time will still be limited.	Analysis – identify problems with current practice	PCK (gap)
e) So if we can have something like they, they can move out for things like research,	Analysis – Justify new practice	New PCK (refine)
f) They get some extra time when they have the gadget the computer g) They get some of the information from the sites given,	Design – conceptualize new practice	New TK (refine)
h) They come to class, we'll use less time to cover so much i) Because they will have come with the, the information from whatever place they were getting it.	Analysis – justify new practice	New PCK (refine)
2. **Researcher**		
a) What do you think? (about? – class teacher) b) Of these proposals that we have to think about learning outside the classroom as well as inside the classroom?	Analysis – clarify new practice	New PCK (refine)
3. Lesson teacher		
a) I think the proposal is good b) Especially if we want to cover the concept c) And the learner gets the content d) The skills will help them in their lifetime	Analysis – justify new practice	New TK (refine)
e) So it means that the time they will have in class, f) It will be like the introduction of the lesson, g) They will be able to get what the teacher is doing and then they take time out of class h) They do their own research i) And they come back to, to finish up what they have started	Design – conceptualize new practice	New TK (refine)
4. Researcher		
a) My question is are there the conditions outside class? b) When you say they should be learning outside class, where will they get the information?	Analysis – clarify new practice	New TK (refine)
5. Teacher Observer 3		
a) I also like to think like in this set up of our class – also like the sources of information might be limited, limited, in terms of eh where to source the information	Analysis – identify problems with current practice	PCK (gap)
b) but when they are outside they have internet and place to source information	Design – conceptualize new practice	New TK (refine)
c) in class we realize that it is the first time they are getting the topic, they may do not have enough information to refer to outside sources	Analysis – identify problems with current practice	PCK (gap)
6. Researcher		
a) But are your students in a position to get information outside class? b) Do they have the skills to source information outside class?	Clarify – identify problem with new practice	New TK (refine)
7. Teacher Observer 1		
a) Yeah actually they have the skills b) Because among the subjects they are offered in school is the computer and they also have ah, a computer laboratory	Clarify – clarify new practice	New TK (refine)

Focus Group Discussion Transcript		Design Process	Knowledge Process
c)	So they can actually go there with their subject teacher, and they can get this information	Design – conceptualize new practice	New TK (refine)
8.	**Teacher Observer 5**		
a)	Maybe still on the same… by using something like a mobile phone, that is ah,	Clarify – clarify new practice	New TK (refine)
b)	It's something that is almost found in every set-up, you can also use it for data, and em, something like that,		
c)	So you are trying to look at the potential that gadget has when you are bringing it in a classroom set-up,	Design – conceptualize new practice	New TK (refine)
d)	So you are trying to enable to embrace the fact that it can be utilized from different perspectives.	Clarify – clarify new practice	New TK (refine)
Source: Focus Group Discussion Transcript, English problem-based lesson, School D, September 2014 Adapted: Koh *et al.* (2015)			

It is a microscopic view of teacher utterances that captured critical moments of changes or transitions in teacher conceptual frames on the object of ICT integration. It is a view that would appear to position teachers more at a 'knowledge deepening' level for more innovative use of technology in practice that would challenge the earlier indications of teachers stuck in 'technology literacy' conceptual frames of thinking about technology. This raises the important question of how advantage may be taken of this incipient development.

From the literature the framework would appear to illustrate teacher design agency potential to break free from what Hammond (2013) describes as the compromising strictures of 'the macro and meso levels of the wider educational system' (p214). Conversely the microscopic view appears to validate Passey's (2010) argument regarding the fault lines in the design of phased approaches such as SIPSE that would seem to judge professional learning prematurely based on initial level activities. He suggests that such frameworks need to adequately consider the wider perspectives of cultural acceptance and involvement of stakeholders from other system levels as integral to the phased development processes from the outset of such initiatives.

In summary, the findings in this theme presented wide-ranging evidence of teacher technology knowledge application that was centred on the use of less sophisticated new technology tools. Teacher lesson plan preparations and applications were mostly dominated by the use of presentation for improving current models of didactic practice and knowledge transfer.

The findings further suggested an object of teacher tool use to be primarily influenced by their conceptual and practical frames of tool affordances for fast tracking student understanding and reproduction learning in the examination oriented cultures of their school and education system environments. Moreover there was evidence of teacher challenges and tensions in the locus of technology control where the teachers appeared uncomfortable with student technology engagement.

Overall the findings appeared to position teacher technology knowledge application at a ‘technology literacy’ level for improving existing practice throughout the two cycles of the SIPSE intervention. However, the use of a microscopic tool for mapping teacher design ideas, suggested tentative transitions to ‘knowledge deepening’ levels. The teacher ideas for use of the computer laboratory as an extension of classroom activities challenged ‘historical-cultural’ belief systems of the laboratory as a specialist zone for technical skills development in schools. The findings further alluded to professional learning processes which do not necessarily adhere to phased approaches such as SIPSE – but which can be more profoundly influenced by opportunities in the wider professional learning eco-system of the school community.

4.3 Capturing the Object of ICT Integration through the TPACKtivity Lens

The TPACKtivity lens convergence of AT and TPACK presents a powerful synergetic capacity (Schul, 2010; Terpstra, 2015) to frame the teacher and head teacher discourses on the object of ICT use in teaching and learning. Figure 4.1 shows graphically a composite view of the convergence mapping the dissonances, tensions, contradictions and opportunities (Engeström, 2010) that were articulated and how they shaped teacher decision making in their usage of new technology tools in their classroom practices. The contradictions and tensions that emerged are illustrated by the bi-directional red arrows.

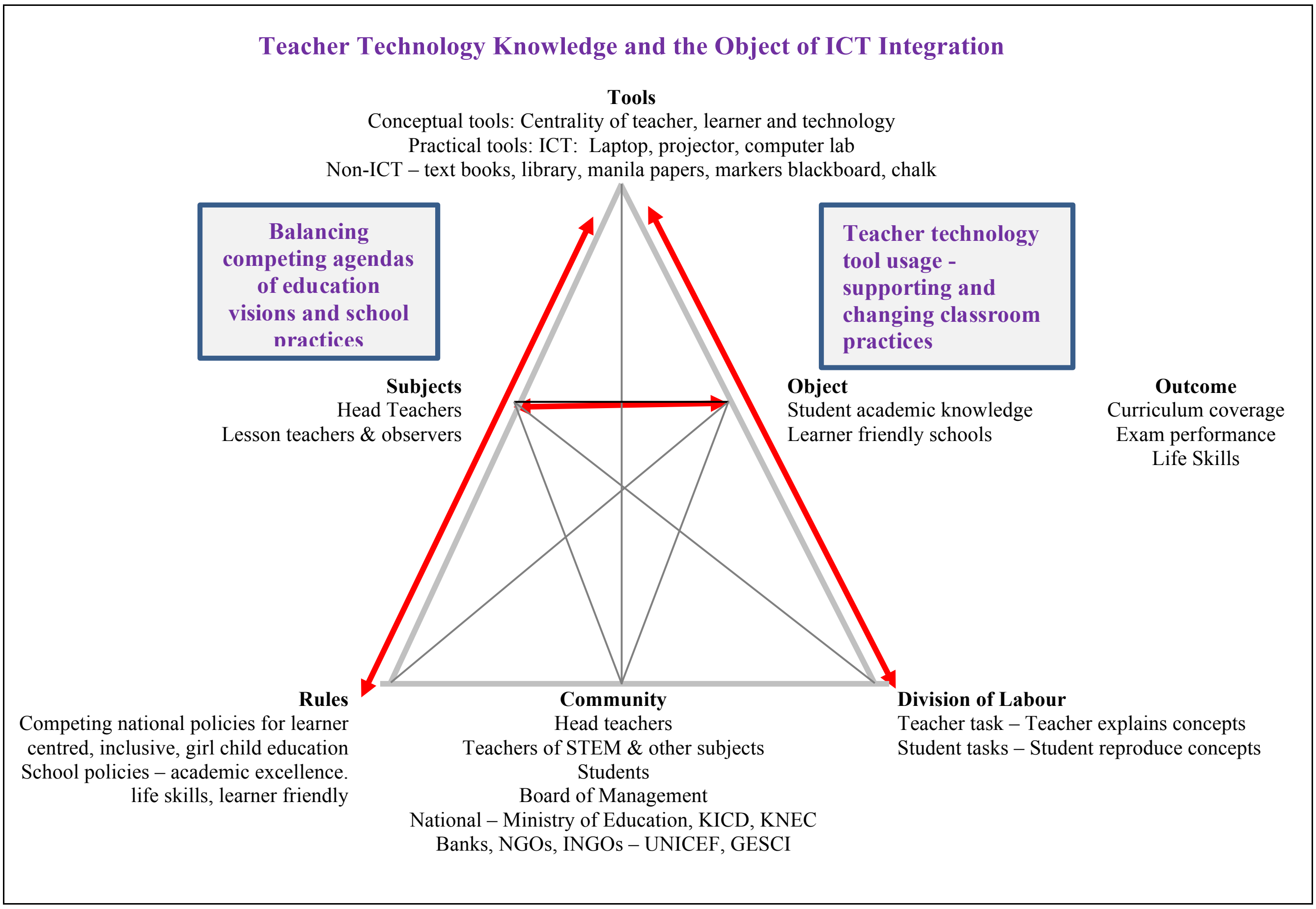


Figure 4.1 - TPACKtivity Mapping of Teacher TK and the Object of ICT Integration (Adapted: Terpstra, 2015)

The top portion of the TPACKtivity triangle identifies the 'subjects' as the school heads, the lesson teachers and teacher observers, the 'object' of ICT use as focused on student academic knowledge and school learner friendly environments aligned to 'outcomes' for national curriculum coverage, examination performance and student life skills related to their psychological, physical, social and spiritual capacities to continually adapt and contribute to their communities and societies. The teachers' technology knowledge application was influenced by contrasting dimensions of 'tool mediation' affordances - centred on 'conceptual tool' affordances integral to discourses on the centrality of the learner, the technology and the teachers; and 'practical tool' affordances inherent in traditional and new ICT tools for improving or changing existing practices. The lower portion of the triangle identifies the 'rules' component illustrating competing and sometimes conflicting school and national regulatory frameworks for learner-centred, inclusive, girl child, life skills approaches and policies, the 'community' component encompassing the teachers, head teachers and students, national institutions (Ministry of Education, Kenya Institute of Curriculum and Development, Kenya National Examinations Council), public and private partners (national and international) of the extended school communities, and the 'division of labour' components describing the teacher and student roles in teaching and learning tasks.

The TPACKtivity lens illuminated two critical tensions influencing teacher decision making in ICT-TK application in classroom practices. First there were imbalances between competing national agendas and visions for holistic learner development and practical agendas for optimizing school attainment of academic excellence in national examinations. Second the teacher ICT-TK applications were limited to supporting existing practices that appeared to be locked into the first tension. As such, the data suggested teacher technology use remaining at a 'technology literacy' level after two cycles of SIPSE. However, a microscopic view of teacher design thinking data pointed to tentative transitions to a 'knowledge deepening' level of technology use aspirations to support more innovative models of teaching and learning inside and outside the classroom. How tentative the teacher aspirations for change were and to what extent the object of ICT integration shifted throughout the teacher professional learning journey will be interrogated at a deeper level in chapters five and six.

CHAPTER 5

Teacher Technology Content Knowledge and ICT use in Problem-Based Learning

5.0 Introduction

This chapter presents findings and thematic discussions related to **Research Question 2: 'What are the characteristics of teacher design for ICT use in STEM teaching and learning mid-way through the SIPSE pilot programme, as evidenced in their approach to problem-based activities?'**

The predominant themes identified in teacher narratives at the programme mid-point related to AT *Rules and Regulations* and TPACK *Technology Content Knowledge (TCK)* and *Pedagogical Content Knowledge (PCK)* constructs. The criterion for selecting the issues for consideration from the narratives was based on how they linked with the *Curriculum and Assessment* and *Pedagogy* system domains of the ICT Competency Framework for Teachers (ICT-CFT) that underpinned the SIPSE programme design. The TPACKtivity lens was used to illuminate the contradictions, tensions and learning opportunities driving teacher decisions and design thinking on technology use for representing and delivering STEM content and activities.

5.1 Teacher TCK – New Technology and New Content Representation

Teacher technology content knowledge (TCK) has been described by Jaipal-Jamani and Figg (2015) as teachers' capacity to identify appropriate tools specific to a discipline, to repurpose tools across disciplines and to use the tools based on personal beliefs, attitudes and comfort levels. Terpstra (2015) contends that teachers' manifestation of TCK in classroom practice will invariably include elements of their pedagogical knowledge (PK). These understandings of teacher TCK with PK elements are used for examining the findings of this theme.

The data suggested three key findings. First the teacher engagement in technology mediated activities enabled them to explore new affordances for content representation and learner understanding in difficult-to-teach STEM topics. Second the teacher tendency was towards historical frames of technology mediation to support convergent knowledge representation and activities for student reproductive learning. Third the tensions and contradictions inherent in an overloaded curriculum and digital content saturation inhibited teacher opportunities to explore technology mediation for supporting more divergent knowledge representation and productive learning activities.

.

The first key finding emerged from participant narratives on new forms of technology mediation to represent STEM content. Table XVIII presents a mapping derived from the TCK focus areas of the teacher problem-based lesson plans and observation notes. It illustrates a unique amalgam of technology affordance, content representation and activity types that emerged from the teacher explorations of TCK in practice in the teaching of STEM content. The mapping format was adapted from frameworks proposed by Angeli and Valanides (2009) and Blanchard, Harris and Hofer (2011).

Table XVIII - Teacher TCK Lesson Focus Areas (Adapted: Angeli and Valanides, 2009; Harris and Hofer, 2009; Blanchard, Harris & Hofer, 2011)

Problem-based Lessons	Technology Content Knowledge (TCK + PK)			Form	No of Students	Lesson Time
	Technology Affordance	**Content Representation**	**Pedagogical Uses - Activity types**			
School A **Biology Topic** The Function of a Nephron	Presentation • Text • video • simulation • images	"Audio, video showing filtration process in different sections of the kidney" Auditory and visual representation of *how the nephron system functions*	***Activity types – 'conceptual knowledge building'*** • ***Attending*** - students gain understanding of abstract concepts (filtrations & re-absorption of materials) from teacher, presentation and video simulation • ***Observing*** - students observe kidney simulation and respond to closed (how many kidneys?) and open questions (why is there no protein in the urine?) • ***Taking notes*** – students recording information from presentation	2	55+	40 mins
School B **Biology Topic** Photosynthesis: Light and Dark Reaction	Presentation • Text, • video • images • simulation	"Reaction of light & equation of photosynthesis on slides" Visualization stages *of light and dark reaction*	***Activity type – 'conceptual knowledge building'*** • ***Attending*** – student gain information from teacher, presentation and video simulation • ***Taking notes*** – students record information from presentation information on role of photosynthesis in life of animals and plants • ***Concept mapping:*** Students complete concept mapping to summarize process of photosynthesis • as homework assignment	1	49	40 mins
School C **Biology Topic** The Role of Hormones in Insect Metamorphosis	Presentation • Text and images • Group work slide orientations Std. Worksheets • Concept mapping • Printed texts	"Technology infusion with the use of images of insects from the internet" Visualization stages of *transformation of organism from larva to adult*	***Activity type – 'conceptual knowledge building'*** • ***Attending*** – student gain information from teacher and presentation ***Activity types – 'knowledge expression'*** • ***Read texts:*** Student extract information from text reference handouts • ***Concept mapping****:* Students complete metamorphosis cycles using concept mapping and text references research • as class group assignment	3	30+	80 mins

Problem-based Lessons	Technology Content Knowledge (TCK + PK) Technology Affordance	Content Representation	Pedagogical Uses - Activity types	Form	No of Students	Lesson Time
School D **English Topic** Sentence Structure, Paragraph Writing, Debate	Presentation • Text and images • Digital story • You Tube video Std. Worksheets • Concept mapping	"Topic interpretation using the clip" Multimodal representation (textual, auditory, visual) to initiate *paragraph and sentence structure representation*	***Activity type – knowledge expression - 'organizing ideas for writing'*** • ***Attending*** – student information gathering from teacher designed and web-based video on story structure ***Activity types – 'language analysis'*** • ***Concept mapping*** – student organization of paragraph structuring – as class group assignment ***Activity types – 'post writing'*** • ***Performance***: Student debate with constructed paragraphs – *mobile phones should be banned in schools*	4	55+	40 mins

Sources: Teacher STEM Problem-based Lesson Plans; Teacher Peer-to-peer Lesson Observations Notes

The mapping serves to illustrate firstly the technology affordances perceived by the teachers in the added value of new forms of multi-media content representation beyond the traditional 'textbook' supported delivery. This was evident in the following teacher commentary on how new frames of digital content changed dramatically historical frames of content availability in the classrooms, empowering first and foremost the teacher capacity to enrich the design of the content delivery beyond the limitation of the textbook.

> I think the most profound discovery was the resources I have at my disposal on the web. They are simply mind boggling!
>
> Lesson Teacher, Mathematics, Questionnaire, School A, March 2015

> To me, actually SIPSE became very important in module 2…, it was where we were introduced to go to learning sites, internet, and that is where we were empowered, after we learned to go to the internet, access information…, because you don't have to rely on a textbook, if a textbook has limited information, then you can access more information in the internet, and eh it was very nice for us.
>
> Teacher 1, Science Problem-based Learning Lesson, Focus Group Discussion, School C, September 2014

> I think according to me, the use of the internet…, some of the things eh, you can get from the You Tube, eh, students can understand those pictures better than just in books, because in just in books, it's ah, it's just something that can be taken, but in the real video, the students can be able to see the reality, that is one advantage of ah, SIPSE, compared to the old methodology of teaching,
>
> Lesson Teacher, Science Problem-based Learning Lesson, Interview, School B, September 2014

> I felt that ah, everything was well used, the technology that is the video clips, the content from the textbook was well placed and the learning objective was… was eh fulfilled
>
> Lesson Teacher, English Problem-based Learning Lesson, Focus Group Discussion, School D, September, 2014

The mapping and teacher narratives highlight their perceptions of the relevance and appropriateness of digital content integration to provide their students with what McDonough and Le Baron (2010) describes as 'alternative perspectives and information sources of content representation' (p36). In this regard the following teacher narratives illuminated their observations and reflections of the multi-media affordances of digital simulation for building student understanding of difficult-to-teach concepts of science models and systems.

> I never did Biology myself, but I looked at the, I was able to learn some bit of expression together with the students and I enjoyed the lesson… and eh, the simulation of the kidney, I think that was an area where I found the students glued to the screen, their eyes were there, quite attentive, and eh, when there was the, the other teacher in (the video) was teaching instead of X [the lesson teacher].
>
> Lesson Observer 1, Science Problem-based Learning Lesson, Focus Group Discussion, School A, September 2014

> [My]ICT main objective [is that] sometimes I want students to visualize so that they are able to see some contents being displayed on video or from visions which will show them the actual process taking place so that they are able to analyse them, imagine how all the processes occur. .., especially for the complex, the complex part of the syllabus, the use of ICT simplifies those concepts so that they can be able to understand.
>
> Lesson Teacher, Science Problem-based Learning Lesson, Interview, School B, September 2014

Of particular note in the lesson mapping was the teacher repurposing of digital tools in lesson design and try-outs to engage the students in *conceptual knowledge building* and *knowledge expression* activities. These are described by Blanchard, Harris and Hofer (2011) as learning activity types designed to build student conceptual knowledge and the development and expression of their own understandings of a given topic. For example, the following teacher narratives in School D illuminated teacher exploration of presentation tool affordances to integrate video story, You Tube and concept mapping tools for deeper learner engagement in language analysis and expression activities.

> I think eh the first clip was good [teacher produced digital story], bearing the fact that eh the people who are involved in the clip were students whom they know, so to me that gave them to be interested, to be keen on what was happening…
>
> Teacher observer 1, English Problem-based Learning Lesson, Focus group discussion, September 2014

> Now according to what I saw, there were several clips [teacher designed digital story and You Tube clips] that were being played in the lesson and they were short and to the point… so I discovered that the clips were presented to achieve short but specific objectives.
>
> Teacher observer 5, English Problem-based Learning Lesson, Focus group discussion, September 2014

> Well I think em at some point in the lesson, the students were divided into groups, and they were to undertake some task [concept mapping], and they were to write that task, or the findings of the task on a worksheet, which they used to present their findings
>
> Teacher observer 4, English Problem-based Learning Lesson, Focus group discussion, September 2014

Other teacher narratives highlighted teacher design reflections on more effective use and repurposing of technology tools to engage learners in deeper levels of knowledge building. For instance the following narratives highlighted teacher reflections on repurposing the use of the concept mapping tool to support aspects of deeper cognition building described by Passey (2011) in terms of 'analysis, synthesis, evaluation, creativity and concept formation' (p8).

> I heard Teacher X [Lesson Teacher] talk of why, why and why is a question that requires a lot of thinking…, when he asked why there is no protein in the urine, I almost said what about when there is protein in the urine… (teacher laughter…), I think that would be brainstorming…., even eh concept mapping can be used to bring in the idea of what happens when there is protein in the urine… how does it happen, how?.. the 'how' question…
>
> Teacher Observer 3, Science Problem-based Learning Lesson, Focus Group Discussion, School A, September 2014

> According to the concept map yeah, it would have been good if em, a number of paragraphs would have been presented to the students, … so for example give them a story, let them deduct from that story, know which is the introduction, which is the body, which topic talks about the introduction, which talks about the conclusion, and then they fill this concept map that they were given…
>
> Teacher Observer 4, English Problem-based Learning Lesson, Focus Group Discussion, School D, September, 2014

The latter narratives, however, suggested an over-emphasis on *conceptual knowledge building activity types* and under-emphasis on *knowledge expression activity types* in the teacher problem-based lesson design and try outs. These observations appear to be substantiated in data extracted from teacher peer-to-peer lesson observation notes as presented in Table XIX. The teacher notes on 'what worked well' have resonance with dynamic models of what Harris, Mishra and Koehler (2011) describe in the literature as *convergent knowledge building activities* (p409), as in the teacher exploration of technology affordances for student engagement to "access", "concentrate", "make observations", "demonstrate understanding", "interact with" knowledge representations that were prescribed, directed and evaluated by the teacher. In contrast the teacher notes on 'what worked less well' would seem to allude to a need for more *divergent knowledge expression activities* (ibid.), in their observations of teacher limitations in exploring technology affordances to assist the learners to "connect", "build", "open", "apply", "evaluate" and "create" alternative forms of knowledge representation and communication.

Table XIX - Teacher TCK Lesson Observation Notes

Schools	**TCK** **What did you think worked well?**	**And less well?**	**Teacher Observers**
School A	• The changing slides creates good stimulus variation • It gives clarity on how the kidney operates • The students easily understood the concept	• Students could be used more to identify parts of the screen • Could the students have connected this to dialysis?	Teacher Observer 4, Science problem-based lesson, teacher peer observation notes, September 2014

Schools	TCK What did you think worked well?	And less well?	Teacher Observers
	• The students access the instructional resources through the video clip		
School B	• Learners watched positively concentrated; • Learners demonstrated understanding as they answered questions; • Enjoyed the lesson and clapped in the lesson (not usual);	• Teacher could have used a concept map to summarize the lesson or group work by the students • Questions could be used to build on the knowledge • Open questions	Teacher Observer 4, Science problem-based lesson, teacher peer observation notes, September 2014
School C	• The teacher applies concept mapping in the PBL to teach the metamorphosis of insect • Teacher - application, evaluation - at each level of learning	Not mentioned	Teacher Observer 1, Science problem-based lesson, Peer observation notes, September, 2014
School D	• The teacher used ICT to project the lesson content and activities • The students made observations and the lesson progressed • The technology excited the students and made them more attentive and made the class more interactive • The teacher did not show any signs of difficulty in using the technology	• A variety of video clips could be used • More time could be allowed for the group discussion session • Questions could be made to cover more levels by applying, evaluating and creating type questions	Teacher Observer 2, English problem-based lesson, Peer observation notes, September 2014
Source: Extracts form teacher peer to peer observation notes – Schools, A, B, C and D, Problem-based Lessons, September, 2014			

The teacher notes present limitations in the data representation of teacher TCK-in-practice due to the lack of broader explanations around their observations. They do, however, seem to echo chapter four themes of dialectical tensions around teacher usage of technology to support existing practices of a teacher-lead didactic model of knowledge transfer. From the literature, Koh, Chai and Tay (2014) relate how teachers do tend to use technology for content delivery and to a lesser extent for stimulating participant interaction. Angeli and Valanides (2009) assess the challenge as situated in teachers' instructional thinking and decision-making that is guided by epistemological knowledge and beliefs 'deeply situated in classroom practices' (p159). Ang'ondi (2013) describes teacher attitudes and beliefs in the context of Kenyan classroom practices as driven by 'a fear of change' where many teachers 'would not want to mess with the status quo thus they would rather do things the way they have been used to' (p25).

Thus, a second key finding illuminated teacher tendencies towards historical frames of tool mediation and content representation. The following narratives illuminated the 'fear factor' element and 'pressure' to achieve curriculum coverage that would appear to cascade through every level of the system hierarchy to the teacher in the classroom and would seem to inhibit scope for innovative technology mediation to support new frames of content representation.

> In Kenya we have 18 or so subjects…, compulsory are 12 subjects and the other subjects are electives.
> School Head 2, Interview, School B, September 2014

> The rush that we have, especially in Kenya, to finish the syllabus, it is extensive, it is quite extensive…, there is this pressure that piles all the way from the president down to the CS [Cabinet Secretary], down to the County Director, down to my principal, down to my head of department, down to the teacher, me, that, you have to finish this syllabus.., so, if you are to finish the syllabus by 31st May…, this forces me to hurry, I do not have time to really plan for the lesson …, these kinds of questioning that I'm going to use, these kinds of devices, ICT devices that I'm going to use…
> Teacher 1, English, End of Project Interview, School B, February 2016

> Ok mine was in terms of workload, some of us have too much in our timetables, you find that taking time to prepare technology lessons, you have to go an extra mile, and maybe you prepare these at night, late at night eh, because you have to catch up with everything
> Teacher 3, Science Problem-based Learning Lesson, Focus Group Discussion, School C, September 2014

A third key finding highlighted digital content saturation that limited teacher capacities to explore more divergent STEM knowledge representations and activities. The data revealed numerous contradictions in the narratives on efficiencies and effectiveness of technology enhanced lesson activities for content delivery. On the one hand many of the narratives highlighted the ease of accessibility and availability of digital content from national institutions and the internet such as the following commentaries from Teachers in School C.

> T3. Right now we have that information with us in the form of CDs [from the Kenya Institute of Curriculum Development][24], the information for the KCSEs,[25] this information we have in CDs, it is on CD for form 4, we are using that CD…
>
> T4. Ok in teaching we have explored more content from the internet, it has given a different knowledge to the teacher and to the learner, if you infuse what knowledge you have from the textbook, and from the internet, you come up with an interesting material for learning
> Teachers 3 and 4, Science Problem-based Learning Lesson, School C, September 2014

On the other hand the data illuminated several teacher narratives pointing to challenges and tensions in identifying appropriate digital content that could be aligned to the curriculum objectives and learning levels of their students. Here teachers in School B commented on issues of depth and breadth in identifying appropriate content from the internet:

[24] Kenya Institute of Curriculum Development has a core function to conduct research and develop curricular materials for all levels of education below the university

[25] Kenya Certificate of Secondary Education

> Ok the ones [video clips on the internet] which were available only, most of them had too many details… so I couldn't get an appropriate one for this level of students, especially one that explains the process, the real live process, yeah and I think if I had more time I would have got that..
>
> Lesson Teacher, Science Problem-based Learning Lesson, School B, September 2014

> You discover that, there are some approaches [on the internet], although it teaches the same topic that we are doing, but the depth that is covered is beyond our student, so, I got it from the, the net, you key in, you're looking at eh vectors, a topic like vectors in Mathematics, to be specific to get the content that specifically addresses our Kenyan learners at their level, a form 2, it becomes a bit tricky, and that is why I was saying, if we can get the correct content, for our level of learners …
>
> Teacher 2, Mathematics, End of Project Interview, February 2016

Other participant narratives illuminated deeper issues on content validation and ownership in the expanded arena of digital content. The following end of project reflections by Teacher 2, School B highlighted potential tensions of the mass incursions of proprietary content in schools that were not government approved and the potential opportunities for engaging teachers in developing more culturally appropriate digital content that drew on their knowledge of local contextual and learner needs.

> *On proprietary content:* Now what happens in our schools, we get these materials, they are not from the government…, they will come into schools, I will buy, we buy, you know as a teacher you go through it and say is it assisting my learner to get a grasp on this concept, if yes, then we buy, so in schools we have so much material from different associations that are not approved by the government…
>
> *On teacher produced content:* I would look at a situation where SIPSE would bring us together [all project teachers to produce digital content]… that is why I say, if we can get that content to be in our level, and that one can only be developed from the, the, the ground, let me call it from the ground, from the teachers involved, because I know our content, I can suggest, because I know our environment, I can suggest if I am making a model, with locally available materials…, [improvised materials for science and mathematics that can be produced as vodcasts for distribution among teachers][26]
>
> Teacher 2, Mathematics, End of Project Interview, School B, February 2016

From the literature McDonough and Le Baron (2010) comment on the profound changes in the nature of content movements from text-based to digitization. Padilha (2013) relates on the greater complexities in the field to ensure the quality of educational resources and content relevance in the emerging digital environments of school cultures. These critical discourses form part of the following theme exploration of ICT and knowledge deepening.

[26] Improvisation is part of the Centre for Mathematics, Science and Technology Education in Africa (CEMASTEA) coursework the teachers attend that introduces an Activity, Student, Experiment and Improvise (ASEI) model of teaching and learning in Science and Mathematics. The improvisation centred on teachers optimizing the use of available resources form the local environment to produce models.

In summary, in this theme there was evidence of teacher engagement with new frames of technology-mediated activities for representing content and building student understandings of difficult-to-teach concepts. Of particular note was evidence related to digital tool repurposing in teacher lesson design and try-outs to engage students in conceptual knowledge building and knowledge expression activities. However, patterns in the data sets suggested an over-emphasis on conceptual knowledge building activity types and under-emphasis on knowledge expression activity types in lesson design and try outs.

The findings highlighted a 'fear factor' that was associated with time and workload 'pressure' to achieve curriculum coverage. The findings further revealed a particularly potent area of tension and opportunity centred on digital content. While digital content offered ease of accessibility and availability from national institutions and the internet, there were challenges in identifying appropriate content aligned to curriculum objectives and learning levels, some evidence of mass incursions of proprietary digital content in schools and a need to engage teachers in developing more culturally-appropriate digital content.

5.2 Teacher TCK – Disruption and New Design

The data in this theme suggested two key findings. Firstly the narratives highlighted tensions perceived by teachers around new technology disruptions of traditional tool mediations of note-taking and questioning in content representation. Secondly the data revealed unexpected narratives that illustrated teacher design thinking to confront traditional STEM content knowledge representation and tool mediation.

The first finding emerged from teacher commentaries that pointed to deepening tensions around new technology disruption of the norms of classroom practices for content representation and knowledge transfer. For example, the following narratives among teachers from School B elucidated a sense of displacement in the teacher conceptual frames on the quality of student *"internalization"* of content with the shift from *"pen*" and paper to new digital technology tool cultures.

> TO3. I saw students writing notes, so that one I thought it worked well, so as the teacher was teaching and they were observing the slides, they were managing to write some notes…
>
> TO5. Some of them were not writing notes so I didn't understand whether that is through the whole thing, they were interested in the watching, but they were not writing anything… so I did not know how to [pause], I don't know where to put them [pause], as others were writing, others were just watching…, so I don't know whether those are the fast learners?

> TO2. Remember writing is another tool that is used by some students to internalize information, (to internalize emmm… Teacher Observer 5), so the taking of notes, the technology must not replace (the pen – Teacher Observer 5; em hem - Teacher Observer 1), the notes that the student needs to internalize, so they all must be writing (writing something – Teacher Observer 1), so that at this time, write that down, so that they have some notes to refer to (OK – Teacher Observer 5), otherwise the excitement is important for the lesson, for them to be with you …
>
> Teacher Observers 2, 3 and 5, Science Problem-based Learning Lesson, Focus Group discussion, School B, September 2014

In contrast the following Teacher 1 narrative reflected an emerging sense of perceptual dissonance on the role of teacher 'note-giving' as the *"simplest"* solution for over-burdened and pressurized teachers.

> You don't have the time [so] what do you do? The simplest thing, you go with your notes, they are here, you read them out, read out notes, this is characterization, now what you are doing today, we are reading a set book, so under page, right… I pity those students very much when I have to go and to teach, with the notes, the read out notes, I feel terrible about it, because I know of other methods that I can use…[from SIPSE]
>
> Teacher 1, English, End of Project Interview, February 2016

The commentary highlighted the dilemmas teachers faced in shifting design frames from established and verified practices of tool mediation for student content internalization in the contextual hothouses of the examination oriented secondary schools. In the literature Engeström *et al.* (2014) described the phenomenon of new tool disruption as challenging teacher 'taken for granted or tacit understandings of every day practices that are often insistently repetitive' (p8).

In this regard the data illuminated a particular set of narratives around teacher traditional 'questioning' mediation that would seem to have created what Koh *et al.* (2015b) describe in the literature as 'cognitive dissonances' (p3) in teacher perceptual frames of these routine practices. For example, the following narratives illuminated teacher perceived challenges in the pacing and sequencing of digital and questioning tool mediations that would seem on one level to have elicited meaningful learner responses (Teacher Observer 3, School C), on another level to have left some learners behind (Teacher Observer 4, School D) and on another level to have identified gaps in teachers' own 'belief mode thinking' (ibid.) about the nature and meaning of knowledge acquisition (Teacher Observer 1, School A).

> Yes I also want to talk about the way it was presented, the content…, it was giving the students enough time to respond, the whole presentation was not very loaded to the level that it would make the lesson lose time, you could find that before the end of the lesson the pupils could respond…,
>
> Teacher Observer 3, Science Problem-based Learning Lesson, School C, September 2014

> Now em, the clips worked well… [but] there's a slight chance, em, of some students, being left behind. The reason is, the question, the questioning-answering technique ah being applied, ah if the

> teacher asks a question and then a mob of the students answers, then it carries the whole class isn't it…, so in a way some of the students might not have understood the concept, but because the majority have answered correctly, then some of the students might be left behind…
>
> Teacher Observer 3, Science Problem-based Learning Lesson, Focus Group Discussion, School B, September 2015

> We didn't have the higher level, the higher level questions, where the students are required to synthesize, analyse, em, it was mostly on the lower level, but, I guess that was the nature, it was the nature of the lesson, there are some lessons again where you can't go to the, the higher level, it requires more of understanding and memorizing.
>
> Teacher Observer 1, Science Problem-based Learning Lesson, School A, September 2014

Other teacher narratives exposed ever deeper levels of 'cognitive dissonances' in teacher interpretations of the changing shape of new and traditional technology-mediated activities in their classroom practices. For instance the following narratives would appear to present contrasting teacher perceptions on content delivery as a fixed entity irrespective of tool mediation (Teacher Observer 1, School C), and as a dynamic entity that may or may not be attributable to digital or traditional tool mediations (Lesson Teacher and Teacher 1, School B).

> I could tell you actually because the only approach we actually use is the Blooms Taxonomy, whether we use didactic teaching, whether we use which method, the criteria will still be the same, ICT will only facilitate, and deliver the content in a better way, an easier way, but the criteria still remains the same.
>
> Teacher Observer 1, Science Problem-based Learning Lesson, School C, September 2014

> The one [activity from the course] [that] I found most useful was eh the questioning techniques. It has really changed my way of asking questions in class…, so that now I always integrate questions on ah low order thinking skills and high order thinking skills…, and in addition the use of ICT, the slow learners in class are really able to visualize what you are talking about, so that one has really changed my way of teaching.
>
> Lesson Teacher, Science Problem-based Learning Lesson, Interview, School B, September 2014

> But there were other methods [from the course] that I knew all along, I learned in college, but which I was not using very well, I am talking about such things as em, questioning, questioning techniques, very simple, but one of the best methods that you can use without any technology whatsoever, and one that can work very effectively for you, and which you can use without looking for anything else, it's the simplest method, em…
>
> Teacher 1, English, End of Project Interview, School B, February 2016

It was interesting to note that the traditional technology tools of note taking and questioning featured strongly in teacher narratives, while discussion on the use of technology to facilitate more in-depth conceptual understanding and application of concept to real world problems did not materialize as expected given the module theme of problem-based learning. For instance the following teacher narratives highlighted the use of questioning techniques and new technologies (presentation and simulations) as tools of convenience for real-time classroom assessment that would seem to be locked into traditional formats of student knowledge acquisition and reproduction to give *"correct information"* and *"perform tasks"*.

> Now from the student presentation and as they present I will be improving the questions to make sure that they give correct information and to [make sure] they acquire depth. After the lesson I will try to bring together their information, their concept in summary using different ways, I have some PowerPoint presentation on clips which will bring together all the concepts now together.
>
> Lesson Teacher, Science Problem-based Learning Lesson, Focus Group discussion, School C, September 2014

> Mainly we are using questioning techniques so that I am able to know at what point they are, whether they understood or not, and then sometimes I give them tasks to perform, if they have understood, definitely they will be able to respond… I take them through the video clip, then I pause, and then ask them a few questions of what is going on in the clip, so as I use the video clip, I probe the learner along the way, just to be sure that they are on course.
>
> Lesson Teacher, Science Problem-based Learning Lesson, Interview, School B, September 2014

From a TPACKtivity lens the teacher exploration of familiar tools such as questioning techniques in the unfamiliar territory of new technology enhanced activities would seem to have articulated the interface of two emerging roles in the narratives. From the AT perspective there would appear to be evidence of a "strangefying" role described by Engeström *et al.* (2014, p8) in the literature as bringing to the surface contradictions in teacher routine classroom practices. From the TPACK perspective there seemed to be more evidence of the teacher 'talk back' role as described by Koh *et al*. (2014) in chapter 4 for elucidating teacher negotiations of design ideas to address routine practice contradictions. A number of authors from both perspectives point to a third role of an outside expert or researcher to assist teachers in challenging their ideas and conceptual frames inherent in routine practices (Engeström *et al.*, 2014; Koh, Chai & Tay, 2014; Boschman *et al.,* 2016). The external researcher role was evidenced intermittently throughout the teacher narratives. The researcher, however, remained cognizant of their 'positionality' (Bourke, 2014) in relation to unduly influencing the relationship with the teachers and their interpretations of the challenges and contradictions.

In this way the second finding illustrated unexpected narratives of teacher design thinking that emerged from the teacher 'talk back' framing tool (Koh *et al.,* 2015a) discussed in chapter four. Tables XX and XXI present transcript extracts from the post problem-based lesson observation FGD conducted in School B. In Table XX it can be seen that the discussion was kick-started with the English Teacher Observer 1's reflection on challenges in balancing new and traditional tool mediation of video and questioning with engaging all learners to *"move with"* and *"expound"* on the content (Lines 1a-g). This surfaced various tensions and dissonances in what turned into a lively and passionate inter-disciplinary teacher discussion. For instance, the analysis justification by the

Biology Lesson Teacher (Lines 2a-e) and Chemistry Teacher Observer 5 (Lines 3a–h) of Science as a closed *"definite"* knowledge domain that presented difficulties for open questioning techniques, triggered several subsequent 'design turns' in the discussion process on the nature of knowledge and knowing in STEM subject content. The teachers' conceptual thinking in these turns seemed to reverberate with Niess's (2008) description in the literature of 'thinking strategically' about TPACK applications that encompassed *'declarative, procedural, schematic and strategic'* (p224) knowledge dimensions.[27]

Table XX - Exploring New Design Frames for TCK-in-practice

Focus Group Discussion Transcript		Design Turn Process	Knowledge Deepening Process
1.	**Teacher Observer 5 – Chemistry**		
a)	I felt em the questioning was good,	Analysis – confirm value of new practice	New PK
b)	If only em we could introduce some more em open questions,	Analysis – identify problems with new practice	New PCK (refine)
c)	The questions asked were very direct and closed,		
d)	They did not offer opportunity for [students] to expound on the same		
e)	I felt em, the video moved too fast, too fast, for the students to move with it,	Analysis – identify problems with new practice	New TCK (refine)
f)	So you have slow students who will not catch up, they'd still be a little bit behind,	Analysis – identify problems with new practice	New TCK (refine)
g)	But of course it was a good lesson… don't be discouraged	Analysis – confirm value of new practice	New TCK
2.	**Lesson Teacher – Biology**		
a)	Most of them were closed because ok…	Analysis – justifying current practice	CK
b)	This is a process that is definite		
c)	And the activities that take place during the process are almost defined…		
d)	I tried to think of open questions, it was a bit difficult… I could only remember one…	Analysis – identify problems with new practice	New CK (refine)
e)	So he is right, I didn't have a lot of open questions…		
3.	**Teacher Observer 5 – Chemistry**		
a)	The lesson was good… I don't have any problems with it…	Analysis – confirm value of new practice	New TPACK
b)	I think the teacher tried her best… to capture everything in the TPACK	Analysis – clarify value of new practice try-out	New TPACK
c)	But what we need to realize, these things do not all come out in one lesson, they cannot…	Analysis – identify problems with new practice	New TPACK (refine)
d)	You will capture some, others will not capture,		

[27] Niess described TPACK 'strategic thinking' as "thinking about the thinking involved in TPACK: *declarative* - knowing that, including definitions, terms, facts, and descriptions; *procedural* - knowing how that refers to sequences or steps to complete a task or subtask; *schematic* - knowing why by drawing on both declarative and procedural knowledge, such as principles and procedural models; and *strategic* - knowing when and where to use domain specific knowledge and strategies, such as planning and problem solving together" (ibid).

Focus Group Discussion Transcript	Design Turn Process	Knowledge Deepening Process
e) Again even the questions, there are topics that are closed, like in Chemistry, I think I would be so closed, because they are facts (Chemistry is factual… Lesson Teacher - Biology),	Analysis - clarify current practice	CK
f) Biology is a bit open, but Chemistry is factual, so some of the questions, some subjects may not, even Mathematics, Chemistry… (em – Teacher Observer 2 – Mathematics),	Analysis - clarify current practice	CK
g) What questions will Teacher X (Mathematics teacher) ask? (laughter)… (I will expect… I will expect definite answers….Teacher Observer 2 – Mathematics) … definite answers (laughter)	Analysis - clarify current practice	CK
h) So… ah, we need to take account of that, that we cannot capture everything 100% in the one particular lesson… because we have to be realistic…	Analysis – identify problems with new practice	New TPACK (refine)
Source: Focus Group Discussion Transcript, Science problem-based lesson, School B, September 2014 Adapted: Koh *et al.* (2015)		

Table XXI shows the rest of the design framing episode from the teacher FGD. Here the role of the researcher can be seen in kick-starting this phase with questions challenging teachers to reflect on their conceptual frames of STEM knowledge dimensions *("Is it that some subjects are more closed than others?...")* (Lines 4a-e). Of particular note was the evolving dynamic of teacher strategic thinking knowledge dimensions in this phase of the discussion. For example, Mathematics Teacher Observer 2's description of their subject domain knowledge that would pertain mostly to a *declarative knowledge* type *("When I ask for the value of x… there's only one value of it")* (Lines 5a-e), but when 'challenged' by English Teacher Observer 1 (Lines 6a-b), extended their description to include some *procedural knowledge* dimensions *("The difference will come in on the methodology…")* (Lines 7a-d). The English Teacher Observer 1's conceptualization of a *schematic knowledge* consideration for Mathematics problem-solving lessons (*"'probability' maybe… isn't there something there?"*) (Lines 8a-g) and the Physics Teacher Observer 4's conceptualization of a *strategic knowledge* consideration for all STEM lessons *("The knowledge we give to the students, or the knowledge we acquire, we are supposed to apply it somewhere…,")* (Lines 10a-d), pushed the boundaries of the teacher discussion to broader and more in-depth levels of thinking strategically about STEM content and knowledge dimensions.

Table XXI - Developing New Design Frames for TCK-in-practice

Focus Group Discussion Transcript	Design Turn Process	Knowledge Deepening Process
4. Researcher		
a) I like your observations…(teacher laughter)	Analysis – identify problems between new and current practice	CK (gap), New CK (refine)
b) I think you have given us a challenge…		
c) Is it that some subjects are more closed than others?		
d) Is Chemistry closed?		
e) Is Mathematics closed?		

Focus Group Discussion Transcript		Design Turn Process	Knowledge Deepening Process
5.	**Teacher Observer 2 – Mathematics Teacher**		
a)	When I ask for the value of x.. (you want it… Teacher Observer 5 – Chemistry; you want the value… Lesson teacher – Biology)	Analysis – justify current practice	CK
b)	There's only (yeah… Teacher Observer 5 – Chemistry)		
c)	there's only one value of it (Yeah…Teacher Observer 5 – Chemistry)		
d)	And the other one you give me is wrong (Yeah – Teacher Observer 5 – Chemistry)		
e)	If it's not the correct one (Yeah – Teacher Observer 5 – Chemistry) so…		
6.	**Teacher Observer 1 – English Teacher**		
a)	There are some aspects of Mathematics that are closed (some… Teacher observer 2 – Mathematics), some	Analysis – describe current practice	CK (gap)
b)	But are there not opportunities for problem solving in Mathematics?	Design – propose new practice	New PCK (refine)
7.	**Teacher Observer 2 – Mathematics Teacher**		
a)	The difference will come in on the methodology…	Analysis – clarify current practice	PCK
b)	How do you arrive at it…		
c)	That's the only thing that's open (emmm – general agreement)		
d)	But the end product (other teacher clapping of hands) is closed, is one, (Is a fact… yes… Teacher Observer 5 – Chemistry Teacher) (laughter)…		
8.	**Teacher Observer 1 – English Teacher**		
a)	I'm challenging you… (laughter…)	Design – propose new practice	New CK (refine)
b)	No… well I'm not so very comfortable with Mathematics, because I'm a language person, the two are far apart,	Analysis – clarify current practice	CK (refine)
c)	But I know there are some, just like X (researcher) is saying,	Design – conceptualize new practice	New PCK (refine)
d)	Some aspects of Maths that can be open		
e)	Maybe as you are introducing a topic, probability maybe, when you bring in some issues out there		
f)	In order to arrive at (inaudible agreement murmurs)		
g)	Now they [students] have to, [work out] the actual calculation (laughter), isn't there something there?		
9.	**Teacher Observer 2 – Mathematics Teachers**		
a)	They'll have to, the others will support me, after that (after that… chorus of other teachers)	Analysis – justify current practice	CK
b)	You'll go where you are supposed to go… (yes… chorus)		
c)	Now when, after that, you will go where you are supposed to go…		
10.	**Teacher Observer 4 – Physics Teacher**		
a)	Yes maybe what I can add is that…	Analysis – identify problems with current practice	CK (refine)
b)	When we say that when we are questioning we only restrict ourselves to closed questioning, on the thing, there, there are some subjects that are closed,		
c)	I think we will be making a mistake, because I think that the knowledge that we give the students or the knowledge that we acquire, we are supposed to apply it somewhere…	Analysis – identify problems with current practice	PCK (refine)
d)	So high order thinking questions must be there, almost in all, in all subjects…	Analysis – justify new practice	New PCK (refine)
Source: Focus Group Discussion Transcript, Science problem-based lesson, School B, September 2014 Adapted: Koh *et al.* (2015)			

A particular feature of the teacher design discourse was that the processes of knowledge deepening were ‘episodic and non-sequential’ (Koh, Chai & Tay 2014, p3). The initial teacher focus on TCK considerations for technology use of video and questioning techniques to better represent STEM concepts, quickly shifted to teacher reflections on STEM knowledge dimensions (CK) and approaches for STEM content delivery (PCK). It would appear that the teachers needed to resolve ‘dialectical tensions’ between the group ‘tacit and explicit’ (Hannay *et al.,* 2013) understandings of how STEM content should be represented – whether as a fixed or fluid knowledge entity. This was needed before they could reach consensus for conceptualizing new technology tools for enhancing STEM content representation (New TCK). Lines 8 and 10 in particular seemed to centre the discussion on teacher understandings of student needs and applications of knowledge in the wider environment as a basis for designing broader conceptual frames and approaches for content representation in STEM teaching and learning (New PCK).

Another feature of the teacher ‘talk back’ discourse was the tendency to subsume the TCK under PCK frames for strategic thinking about STEM knowledge and knowledge building approaches. In the literature, Hofer and Harris (2012) identify challenges in TCK articulation in in-service studies and explain that experienced teachers may unknowingly include knowledge about technology as integral to their curriculum and pedagogical content knowledge applications. This may explicate gap areas in the teacher narratives where technology disruption of traditional tools, techniques and approaches seemed to dominate the discourse.

The teacher debate highlighted a deeper issue reported by Akyeampong (2016) in the literature on African student performance in Mathematics and Science (MS) international studies where they perform well in ‘factual knowledge and procedures’ (p5) that mirrors the teacher ‘talk-back’ pre-occupation with STEM ‘factual’ content knowledge representation and transmission. Yet Akyeampong relates student under-performance in ‘reasoning and analysis’ critical ‘to secure a transformative shift in Africa’s development’ (ibid.) that would echo Teacher Observer 4’s solitary voice and argument for developing students’ higher order thinking capacities for understanding and applying MS knowledge *“somewhere”*.

In summary, in this theme there was evidence of teacher perceived tensions and dissonances around new technology disruptions of traditional tool mediations in content representation. A potent feature of the disruption centred on teacher perceptions of technology interference in the cultural practices of student note-taking, teacher note-giving and teacher questioning techniques as part of their established and verified traditional toolkit for dealing with the contextual pressures of examination-oriented secondary school cultures.

Expected themes on depth of content understanding and application to real world problems that were at the core of the knowledge deepening cycle were not evident in the teacher narratives. There was, however, evidence of ‘cognitive dissonance’ in the teacher discourse in relation to contrasting perspectives on the nature of STEM content knowledge as a fixed or dynamic entity. Yet data drawn from teacher design thinking mapping illuminated evolving and dynamic strategic thinking capacities of the teacher community to challenge contradictions inherent in traditional routines and understandings of STEM subject content knowledge and tool mediations.

5.3 Capturing Teacher Technology Content Knowledge through the TPACKtivity Lens

The TPACKtivity lens in this theme as presented in Figure 5.1 shows a changing activity system of teacher TCK applications. The 'subjects' in this activity system are identified as the lesson teachers and teacher observers of the problem-based lessons.

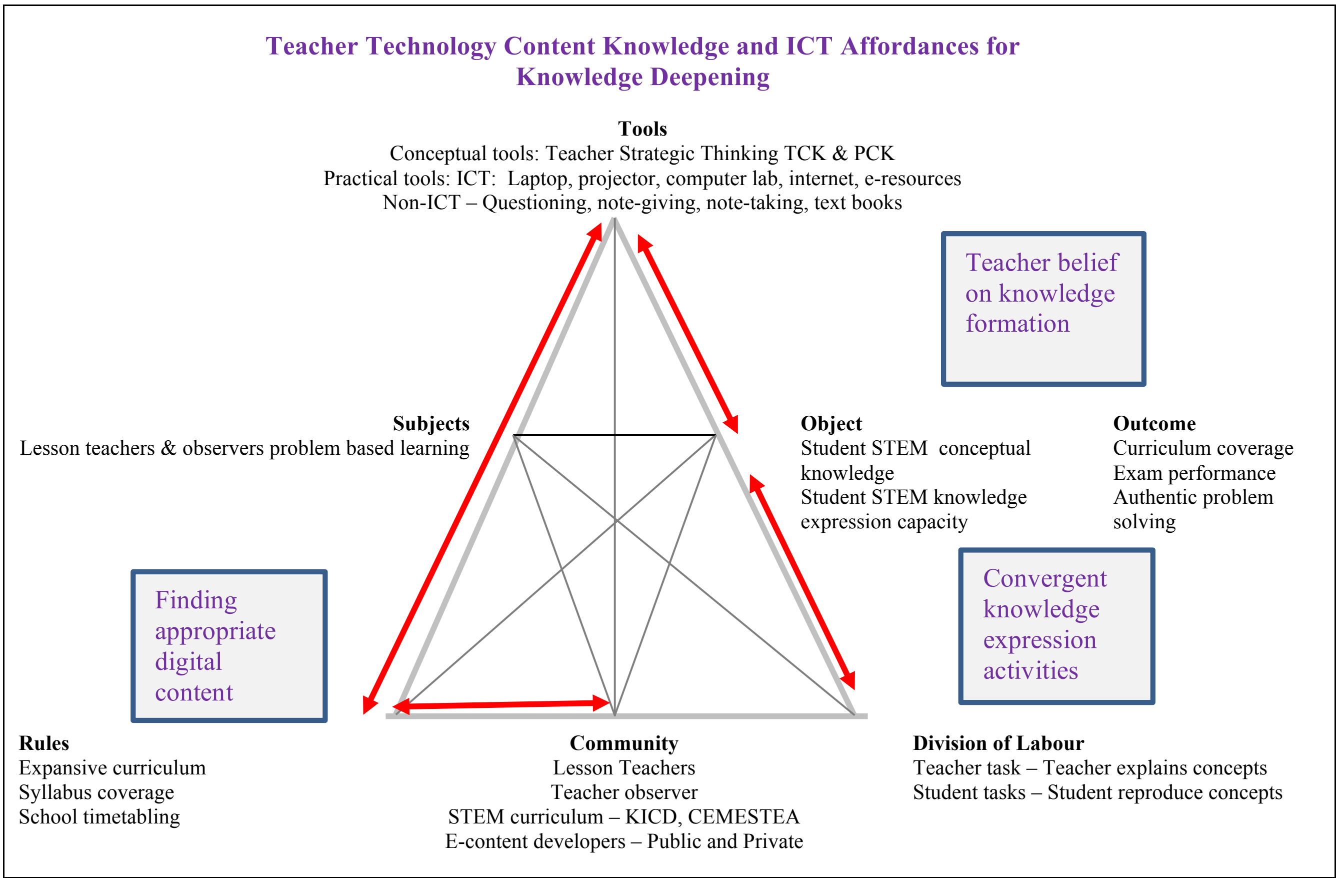


Figure 5.1 - TPACKtivity Mapping of Teacher TCK Applications (Adapted: Terpstra, 2015)

The teachers' 'tools' integrate new conceptual tools of teacher strategic thinking about technology content knowledge (TCK) applications that were subsumed into their strategic thinking about pedagogical content knowledge (PCK) applications. The tools further incorporate additional new technology tools of the 'internet' and 'e-resources' and traditional tools of 'questioning', student 'note-taking' and teacher 'note-giving' mediations. The 'rules' present additional regulatory dimensions of the national expansive curriculum, syllabus coverage and school rules for lesson delivery and time tabling. The 'community' shows new additions of national institutions affiliated with STEM curriculum development (Kenya Institute of Curriculum Development and the Centre for Mathematics, Science and Technology Education in Africa) and e-content developers (public and private). The Division of Labour is unchanged from the TK TPACKtivity mapping of teacher directed teaching and student reproductive learning.

The key tensions and contradictions inherent in teacher technology content knowledge applications were three. The first centred on teachers' tendency towards historical frames of new technology mediation to support teacher directed convergent activities for student reproductive learning and content representation. The second focused on the teacher perceptions of an overloaded curriculum and digital content saturation (internet and providers) which inhibited their capacities to find appropriate e-content for more divergent learning activities and content representation. The third tension was illuminated in teachers' perceptions of new technology disruptions of traditional tool mediations of note-taking and questioning. The third tension underscored deeper cognitive dissonances in teacher beliefs about STEM content and knowledge representations.

Notwithstanding the tensions and contradictions, the views illuminated by the teachers in narratives, observation artefacts and teacher design team discourses positioned the 'object' of technology mediation as focused on two complementary domains of building student conceptual knowledge and student capacities in knowledge expression. While the latter object may reflect teacher aspirational views emerging from group cognitive design reflections, it would nevertheless represent a significant indication of changing teacher perceptual understanding of technology affordances that in turn can change and deepen STEM subject content and knowledge representation in classroom practice.

As in chapter four these general and microscopic views of teacher design thinking and changing perceptual understandings raise questions of how advantage may be taken of these incipient developments for design of future professional learning models. The following chapter will expand on these issues and discussions in the final findings theme exploring the development of teacher technology pedagogy knowledge and new design frames for 21st century models of teaching and learning.

CHAPTER 6

Teacher Technology Pedagogy Knowledge and ICT use in Project-Based Learning

6.0 Introduction

This chapter presents findings and thematic discussions related to **Research Question 3: What are the characteristics of teacher design for ICT use in STEM teaching and learning at the end of the SIPSE pilot programme, as evidenced in their approach to project-based activities?**

In this theme, participant narratives from the end-point data sets predominantly linked to AT *Division of Labour* and TPACK *Technology Pedagogy Knowledge (TPK)* sub-themes. Here the criterion for selecting the issues for consideration from among the participant narratives was based on how they related to *Organization and Administration* and *Teacher Professional Learning* system domains of the ICT-Competency Framework for Teachers (ICT-CFT) that underpinned the SIPSE programme design. The TPACKtivity lens was used to examine 'practical' and 'unique' patterns of teacher technology and pedagogy mediations to support STEM teaching and respond to student 21st century learning requirements.

6.1 Teacher TPK – Designing New Spaces for 21CL

Jaipal-Jamani and Figg (2015) describe teacher technology pedagogy knowledge (TPK) as a practical set of teaching competencies (e.g. classroom management, student differentiated support, learning assessment) 'to plan and implement technology enhanced lessons' (p142). Ouyang (2015) speaks of 'unique' patterns of teacher capacity emerging through the adaptation of technology and pedagogy to support content and meet learner needs (p504). These understandings of emerging practical and unique features of teacher TPK-in-practice form the basis for examining the findings of this final theme.

The data suggested three key findings. First, teachers demonstrated a shift in their conceptual frames for designing project-based learning activities that enhanced 'knowledge sharing' models of teaching for deeper student involvement. Second, the shift in teacher conceptual frames appeared to open up a reciprocity in the roles of teachers and learners for co-teaching and co-learning and for 21st century deeper learning. Third, tensions and contradictions reverting to recurring themes of time, curriculum and the organization of learning spaces for technology integration continued to challenge teachers in their exploration and design of new models of innovative practices.

The first key finding emerged from the teacher design of webquest project-based lesson that integrated for the first time a more balanced 'knowledge sharing' teaching model for more active involvement of teachers *and* students. Table XXII presents a comprehensive mapping derived from the TPK focus areas of the teacher project-based lesson plans and teacher observer notes. The table illustrates the pedagogical uses of technology that the teachers planned and the traditional and emerging new 'models of teaching' (Jaipal-Jamani & Figg, 2015, p145) that the teachers explored. As succinctly noted by the School A Mathematics Lesson Teacher, they integrated a *"mixed grill"* of pedagogical approaches.

Table XXII - Teacher TPK Lesson Focus Areas (Adapted: Angeli & Valanides, 2009; Harris & Hofer, 2009; Blanchard, Harris & Hofer, 2011)

Project-based Lessons & Teachers	Technology Pedagogy Knowledge application				Form	No of Students	Lesson Time
	Technology Affordance	Content Representation	Pedagogical Uses				
School A: Mathematics Lesson Teacher **Topic** Loci	Presentation • Graphics • Geometrical Shapes Student worksheet • Questions • Hyperlinks • Spreadsheets	• Presentations identified on internet website • Visual representation to revise and investigate different constructions of geometrical figures	***Lesson 1: Teacher Activity type: 'Consider''*** Teacher use of PowerPoint • *To demonstrate:* to revise geometric figure concepts • *To define a problem:* to orient webquest group tasks with investigation questions on loci constructions and applications • Teacher note: I used a 'mixed grill' of pedagogical approaches	***Lesson 2 – Student Activity type: 'Consider and produce'*** Student use of web quest • *to investigate concept:* to investigate loci inquiry questions • *to read text:* to use internet for investigating different scenarios where loci can be applied to real life • *to produce a representation:* to present group work using manila papers	*4*	*50+*	*80 mins*

Project-based Lessons & Teachers	Technology Pedagogy Knowledge application				Form	No of Students	Lesson Time
	Technology Affordance	Content Representation	Pedagogical Uses				
School B: Mathematics **Lesson** Teacher **Topic** Trigonometric Graphs – Determining wave parameters	Presentation GeoGebra demonstration Blackboard orientation • Questions • Hyper links • Text books references	• analysis, manipulation and applications of 'periods' based on given equations	***Lesson 1: Teacher Activity type: 'Consider'*** Teacher use of GeoGebra software/ blackboard • *to discuss:* to explain and elicit discussion, • *to investigate:* to create inquiry questions on prediction and verification of wave period parameter problem tasks	***Lesson 2 – Student Activity type – 'Consider, create and evaluate'*** Student use of webquest • *to discuss:* to organize team project wave parameter task; • *to read text:* to research and produce chart of graph trigonometric functions • *to teach a lesson:* to present data findings to class; • *to evaluate:* to conduct peer-to-peer evaluation of other group data presentations	*4*	*45*	*80 mins*
School B: English Lesson Teacher **Topic** Report writing – Health Hazards in Our School	Presentation • Text, images Student Handout • Report writing styles	• images of official newspaper reports on international disaster scenario – story of Titanic • exemplary model and guideline of official report writing styles	***Lesson 1: Teacher Activity type: 'Organize ideas for writing'*** Teacher use of PowerPoint • *to sequence and outline:* explain concepts of report writing; • *to choose form/ genre:* initiate discussion on examples of report writing;	***Lesson 2 – Student Activity type – 'pre-writing, organizing ideas for writing and sharing'*** Student use of web quest • *to brainstorm:* to organize ideas for school health hazard investigation; • *researching:* to carry out school community research to gather information, form opinions, discuss and agree on judgements and write report; • *sequencing:* to use word software tool to report to class, principal and extended community	*3*	*48*	*120 mins*

Sources: Teacher STEM Project-based Lesson Plans; Teacher Peer-to-peer Lesson Observation Notes

The teacher webquest lesson mapping would seem to reflect for the first time in the teachers' professional learning journey more pronounced shifts in their conceptual frames of technology and pedagogy affordances from enhancing 'knowledge transfer' to enhancing 'knowledge sharing' (Passey, 2014, p8) activity types. For instance the following lesson teacher reflections on the student webquest presentations would suggest teacher emergent understanding of TPK affordances for enabling what McDonough and Le Baron (2010) describe as 'student creation, collaboration and prediction of knowledge' (p22).

> I think the level of learning is more in depth, in that the students look for all the materials available. Ah…for the teacher I look for the necessary material available. But for them they go for every material available… There was a formula they introduced there, it was a physics formula or something like that …, you see we rarely use that [Physics formula integration] in Mathematics..., so it means they go for any information available…, and then they use material. So even where you would have assumed, for them they went for everything and that is a plus, so it is for the teacher not to do the clarification.
>
> Lesson Teacher Mathematics School B, Project-based Learning Lessons, Focus Group Discussion, School A and B, February 2015

> There were a few who were off the mark of course. But the larger majority I think managed to get the concepts right, and eh… they were able to present their findings and eh relate them to what we had done…, and eh… even the questioning … I think I like what my friend teacher X (Mathematics Teacher, School B) there has said … the questioning from the other students kind of tells you that eh.. they have actually understood what they were doing.
>
> Lesson Teacher Mathematics School A, Project-based Learning Lessons, Focus Group Discussion, School A and B, February 2015

> The greatest impact I think em the problem and project-based learning has on the student is em… the level of involvement in finding a solution to problem. Ah… the learner is fully involved… the solving is in the hands of the learner. And with that I think we have a deeper understating of em the various ways which you can use to do things.
>
> Lesson Teacher English School B, Project-based Learning Lessons, Focus group discussion, Schools A and B, February 2015

The second key finding elucidated a shift in teacher conceptual frames that appeared to open up a reciprocity in the roles of teachers and learners for co-teaching, co-learning and for 21st century deeper learning. From an activity theory lens the shift described by the English Teacher in their *"deeper understanding in various ways to do things"* would represent a 'zone of proximal development' (Vygotsky, 1978, p86) that was 'symmetric' in challenging the conventional 'asymmetric relations' between mentor (teacher, peer or more knowledgeable other) and learner (Roth & Radford, 2010, p388). The teacher webquest design for teacher-lead activity types in lesson 1 (to *"consider"* and *"organize ideas"*) and student lead activity types in lesson 2 (to *"produce", "create", "evaluate", "write"* and *"share"*) would appear to have created a 'reciprocity' (ibid) between teacher and learner roles and agency that literally took the teachers by surprise. For example, the following teacher narratives encompassing expressions of teacher *"learning"* and *"underestimation"* of their student capacity to engage in group dynamics of problem solving and knowledge sharing revealed an emerging teacher articulation of student-to-teacher as much as student-to-student 'co-learning' (Murphy & Beggs, 2006, p1).

> In the first one [Mathematics observation lesson] I learned a lot. I am not mathematician really, but at least I learned some few things in that subject on loci and the kind of things students mentioned like tethering a cow and the links to loci and the sling that was used by Student X when it was swung and then thrown - at least that was impressive. [In the second Mathematics observation lesson] I think the girls did a good job. They are quite confident and they at least they interacted with the subject and themselves. Each one of them had time to present and learn from one another.
>
> Teacher Observer 1 School A, Project-based Learning Lessons, Focus Group Discussion, Schools A and B, February 2015

> We sometimes underestimate our students. The ideas that they came up there - opens up your mind to what they can do. Their suggestions, for example they are the ones that reported that, we can bring our report to make the community aware of what is going on, that they were to translate that [the report] to the various languages, Swahili and such, the idea of the rest of the community benefiting from their research. So em… that goes to show that they are very capable individuals these students. And they are even more capable when they come together as a group… so you can imagine that you have several of them now thinking and contributing… it goes to emphasize the power of group work… effective group work can solve lots of problems.
>
> Lesson Teacher English School B, Project-based Learning Lessons, Focus group discussion, Schools A and B, February 2015

From a TPACK perspective the teachers' *"mind shifts"* as to what their learners *"can do"* (English Lesson Teacher, School B) would seem to have challenged their fixed beliefs in traditional teacher centred 'knowledge transfer modes' (Passey, 2014, p15) of teaching that dominated the problem-based lesson discourses in chapter five. For instance, in the following teacher narratives of note are the 'knowledge sharing modes' (ibid., p16) that entered the discourse in terms of teacher *"agreement"* on their student capacity to *"take the lessons"*, to *"research"*, to *"learn more"* and engage in tasks of *"'higher levels of difficulty"*.

> To me I think eh the lessons that we have observed, we are in agreement that the students really understood the concepts… and the reason is because they themselves, are the ones taking the lessons. They have all the time to research, both on ICT and non-ICT - and they are able to learn more…, and they are ones that are even taking all the… unless they are being given directions from the teacher, much of the work is being done by the students.
>
> Lesson Teacher English School B, Project-based Learning Lessons, Focus Group Discussion, School A and B, February 2015

> In my setting of the task there were those [Mathematics] tasks I thought had a higher level of difficulty and I thought that there are some questions the students would struggle with. But to my amazement

the areas I expected them to struggle are actually not… they were quite comfortable with, and that I found them challenged in other areas, in areas where I thought it would probably be straight forward. And so sometimes maybe - what we think may not necessarily be true of the group that we are dealing with.

Lesson Teacher Mathematics School A, Project-based Learning Lessons, Focus group discussion, Schools A and B, February 2015

The Mathematics teacher's reflection on what teachers think is *"necessarily true"* of their student problem-solving capacity reflected a pattern of developing conceptual frames in the teacher narratives around their student 21st century learning potential and capacities for 'problem-solving, collaboration and knowledge construction' (Koh *et al.*, 2015b, p2). For example narratives extracted from teacher observation notes of the student webquest presentations illuminated teacher critical reflections on their student incipient 21st century learning capacities (Table XXIII). The contrasting elements in their observations of student *"good and clear presentations", "too fast", "worked like a tag team", "some members inaudible", "a lot of analysis", "more students should have been involved"*, appeared to confirm shifting frames in their understanding of the webquest project-based model affordances for student understanding of and meaningful engagement with concepts.

Table XXIII - Teacher Observation Notes - Student Web Quest Presentations

Observation domains	School A Mathematics PBL	School B Mathematics PBL	School B English PBL
Group Organization	• Presentation clearly given and quite organized • Too fast • As the group presents they need to do the work on the chalk board	• The charts were well illustrated and sequential • Presentation very neat, clear with detailed notes provided	• Good organization of report information by the group lead
Group Content	• Were able to answer question well • As the group presents they need to do the work on the chalk board	• Mathematical facts were well stated & explained • The content contained all the facts with conclusions made giving examples	• Low and high order questions used
Group Presentation	• Very effective with the content clearly presented and illustrated • Should have used bigger manila paper • For every case they should have used a manila chart	• The presentation was clear and to the point • Very effective with many presenters presenting the group work	• More students should have been involved
Group Research	• Group did the work with a lot of analysis based from effective presentations made • Okay • But they should have mentioned the sources	• Data presented is quite accurate • Effectively done and quite organized	• Good interviews around the school; • Information collected from library and internet
Group Communication	• Teacher interacted with different groups to explain some points • From the discussion group members collaborated and worked well together	• All members of the group were involved in the presentation and worked like a tag team – a very good presentation • Excellent	• Good group collaboration to prepare reports on computers

Observation domains	School A Mathematics PBL	School B Mathematics PBL	School B English PBL
	• Some members were inaudible • Well done		
Teacher Observers	Teacher Observer 1 (English), Teacher Observer 2 (Physics), Teacher Observer 3 (Chemistry), Teacher Observer 4 (Biology) School A	Lesson Teacher (English, School B). Teacher Observer 3 (Chemistry, School A), Teacher Observer 2 (Physics, School A),	Teacher Observer 3 – English (School A)
Source: Extracts from teacher student project observation notes – Schools A and B, Project-based Lessons, February, 2015			

Critical aspects of 21st century learning have been described in the chapter two literature by Voogt and Roblin (2010, 2012). The authors' meta-review studies of 21st Century frameworks enabled them to categorize 21st century learning into *cognitive, metacognitive, sociocultural, productivity,* and *technological* dimensions.[28] The following narratives present teacher reflections and perceptions of several aspects of these dimensions beginning to manifest in student behaviours during the English and Mathematics webquest lesson processes and product presentations.

For example Teacher Observer 1's perceptions of student "*original"* thinking in the English report-writing webquest lesson that involved them in devising solutions to real world problems affecting the whole school community, touched on elements of a 21st century *cognitive and creative thinking* dimension for authentic problem solving.

> I think *the girls were quite original, it was not something that was copy paste, they even said it themselves that that went round, interviewing some workers, teachers*, even to the library, they read about the problems that can arise from using public toilets and also the internet, also helped them in getting some information on the same.
>
> Teacher Observer 1 School A, Project-based Learning Lessons, Focus Group Discussion, Schools A and B, February 2015

The Teacher Observer 2's reference to *"student knowing what they need to prepare"* in their observations of a maths webquest project, suggested teacher perceptions of nascent student 21st century 'metacognitive' skills for self-regulation to take responsibility for their own and group learning and to take ownership for more in-depth preparation of the group task and presentation.

28

- ***Cognitive skills*** emphasize the development of students' critical and creative thinking with complex real-world problems;
- ***Metacognitive skills*** supports student engagement in the self-regulation required for learning-to-learn;
- ***Sociocultural skills*** emphasize learning experiences that help students to develop competencies for communication, collaboration, and conflict resolution;
- ***Productive skills*** embody what students need to learn and be able to do in order to develop productive and efficient work processes;
- ***Technological skills*** play a critical role in enabling student 21st century learning and information literacy for productive work practices.

(Voogt and Roblin 2012, cited in Koh *et al*., 2015b, pp539-540)

> The web quest it is involving students a lot. It will make them to research more. *If students know that they will be asked questions as they present, they would go for more content so that they will be prepared.* Then the group work. They worked very well…, so some students would not stay behind thinking that others should present. In the maths lessons in School B, *all of the students in the groups were presenting, they were answering question, they will go in front each and explain something*, so that the students were really involved.
>
> Teacher Observer 2 School A, Project-based Learning Lessons, Focus Group Discussion, Schools A and B, February 2015

The English Lesson Teacher's observations of their student capacity to use English project-work knowledge for *"everyday applications",* suggested teacher reflection of student incipient 21st century socio-cultural capacities for collaboration, communication and application that reached beyond the contexts of their classroom and their homes to the wider school and local community.

> So they have a different understanding of what they can do together. They can actually do bigger things for the school. *They can help the community to solve issues… because the project that [they] have here … about the risks to them… the various areas that can cause problems to their existence, like health hazards*. They were able to pin-point that very easily, not just to pinpoint the problems but also give solutions to them.
>
> Lesson Teacher English School B, Project-based Learning Lessons, Focus Group Discussion, Schools A and B, February 2015

The Teacher Observer 1's observations of a maths webquest student presentation which suggested recognition of embryonic student 21st century *productivity* skill elements for *"everyday applications"* of math concepts to solve routine and complex problems efficiently.

> The approach to me with eh, like eh, the mathematics class, the first class that we saw for Mr. X [Mathematic Teacher, School A]. I think the approach was really good… and it was eh…with the applications… the students could quickly get the idea from *the applications that we, that they encounter …have come into almost each day*.
>
> Teacher Observer 1, Project-based Learning Lessons, Focus Group Discussion, Schools A and B, February 2015

The Teacher Observer 4 observation of *technological* elements for *"web-based research"* hinted at teacher perceptions of student 21st century technological skills capacity needs for empowering self-directed research, learning and presentation of new knowledge.

> I think the method that we have used today is the best method… because this method allows the students enough time *to carry out their research [on the web]* and to carry out their presentations.
>
> Teacher Observer 4 School A, Project-based Learning Lessons, Focus Group Discussion, Schools A and B, February 2015

Overall, the teacher discourse appeared to present a reciprocity between teacher and student use of the webquest as a 'cognitive tool' (Angeli & Valanides, 2009, p161) to co-construct meaning and co-develop understanding around problem-solving tasks. The potency of the teacher-student reciprocity was captured in the following Teacher Observer 1's reflection on the transformation of the student role into *"eloquent teachers"* that challenged the *"traditional methods"* of the teacher's role of *"just standing there"* and "*talking to them"*.

> I think ah there are some students like in Teacher X's [Mathematics Teacher School A] we are teachers of the same class - but they have never talked in class. But today they were there teaching mathematics quite eloquently and I was impressed. So I am sure if he had not given that topic and continued doing his traditional method of just standing there and just talking to them they will never have talked. I think it is a plus.
>
> Teacher Observer 1 School A, Project-based Learning Lessons, Focus Group discussion, Schools A and B, February 2015

The Teacher Observer 1's reflection would hint at a nuanced transformation in teacher conceptualization of teacher-student communication roles. It was as if the communication factor was pivotal in disrupting 'teacher traditional beliefs about how students learn' (Ozgum-Koca *et al*., 2011). The teacher webquest narratives and assessments revealed evidence of an emergent student voice in the lesson try-outs and its powerful capacity to raise teacher awareness about the possibilities for 21st century deeper learning frames that go 'beyond acquiring mastery or expertise in a discipline' (Asia Society, 2015, p24).

.

The third key finding, however, exposed tensions and contradictions inherent in the webquest models of teaching that reverted to recurring themes discussed in previous chapters of time, curriculum and the organization of learning spaces for technology integration. The teacher narratives continued to elucidate challenges inherent in organizational and learning spaces for integrating a webquest model of teaching into their daily practices. The following teacher reflections were illustrative of the contextual barriers that appeared to continually lock the teacher discourse into the 'grammar of schooling' syntax (McDonough & Le Baron, 2010, p10) related to *"time"* and *"curriculum coverage"* that inhibited experimentation with innovative practice.

> My challenge and difficulty was time, time, time. We need to plan project-based learning in a better way if we are not to use too much time… and the time is limited in which we are supposed to put forward the curriculum. So that is the greatest challenge. Otherwise I think it was a very good method of em… of even teaching.
>
> Lesson Teacher English School B, Project-based Learning Lessons, Focus Group Discussion, Schools A and B, February 2015

> You only managed to get a lot of time because his colleagues are not around – but eh were it to be used to in their specific 40 minutes [time allocated for lessons], he [the English lesson teacher] would not have reached anything, but we spent [at] most like 3 lessons and it was quite effective
>
> Teacher Observer 1 School A, Project-based Learning Lessons, Focus Group Discussion, Schools A and B, February 2015

Another recurring theme throughout the teacher discourses was the issue of 'classroom organization' and 'technology access' as essential conditions for trying out new models of teaching and learning. The following teacher narrative reflected the issue in his observations of daily *'challenges'* of student classroom movement so as to *"interact with appropriate technology"* and his *"campaign"* for organizing *"ICT friendly classrooms"* with *"buy-in"* from teachers and students.

> The other thing I think you have observed that there is also a challenge in that eh… the students are moving from eh… their class to a different area so that they can come and interact with the appropriate technology. It's not available in their classes. If it were… we would not have the wastage of time in between the movement.
>
> Lesson Teacher Mathematics School A, Project-based Learning, Lessons Focus Group Discussion, Schools A and B, February 2015

> Of course I plan to continue using ICT in my teaching. I'm currently engaged in a campaign to make the classrooms more ICT friendly with my Principal. I hope to change the mind set of my colleagues as well as the students to buy into the idea of ICT integration.
>
> Lesson Teacher Mathematics School A, Project-based Learning, Questionnaire, March 2015

The tensions may explain some gaps in the teacher TPK discourse which seemed fixed on issues of more student involvement but lacked reflection on the affordances of new technology and pedagogy to address deeper issues of their student differentiated learning needs and differentiated learning support. The teachers' dilemmas are echoed in the literature debates on the implications of 'changing pedagogical practices' for a corresponding appraisal of 'how learning spaces are conceptualized' (Butler *et al.*, 2013, p10) and of how 'time, space and people' (Asia Society, 2015, p25) in school organizations need to be used differently. Voogt and Roblin (2010) assert that 21st century learning demands significant curriculum restructuring and corresponding needs for new teaching methods, assessment procedures and 'a comprehensive use of technology to support the mastery of 21CL skills' (p29). In Kenya, school reform in the organization of learning and learning spaces is a priority with the announcement in March 2016 of a new curriculum 'focused on imparting skills to learners' (Wanzala, The Nation, March 31, 2016). The critical issues and discourses on the 'fit' of new models of teaching and innovative practice into conventional settings of school practices form part of the final theme exploration in the following section on designing a professional learning model for a 21st century learning school and society.

In summary, in this theme there was evidence of new teacher design frames in project-based learning that enhanced 'knowledge sharing' models of teaching for deeper student involvement and engagement. There was evidence in the narratives of an emergent student voice and its powerful capacity to raise teacher awareness about the possibilities of 21st century learning models that went beyond student acquisition of STEM content knowledge. The findings suggested a new potency in teacher-student reciprocal cognition and communication for transforming practice and for developing more symmetric relations of co-teaching and co-learning.

However, the findings also evidenced tensions and contradictions across the teacher narratives of continuing issues of time, timetabling, curriculum coverage, classroom organization and technology access. The findings could explain gaps in teacher narratives on new technology and pedagogy affordances for addressing deeper issues of student differentiated learning needs and support. These gaps will be interrogated further in the following final sub-theme of the chapter.

6.2 Teacher TPK - Designing a 21st Century Professional Learning Model

The data in this final sub-theme illuminated four key findings. First, how teachers' collective design presented a key resource for mapping future pedagogy responses to the 21st century learning needs of their students. Second, how collective and continual teacher conversations on tentative changes and successes presented a basis for effective professional learning. Third, how disconnects between national and school-based vision and action presented tensions that limited teacher spaces for innovative practices. Fourth, how broader engagement of multi-level school system dialogues for vision and action are needed to support continuity in teacher professional learning beyond interventions like SIPSE.

The first key finding elucidated teacher design frame mappings for a tentative future pedagogy responsive to the 21st century learning needs of their students. Tables XXIV and XXV present transcript extracts of the teacher post project-based learning lesson FGD conducted with Schools A and B. What is of note in this final mapping was the trajectory of teacher design thinking for seeding, negotiating and adapting solutions for integrating the 'inquiry based collaborative nature of learning' (Butler *et al.*, 2013) inherent in webquest into their daily routine practices.

In Table XXIV it can be seen that the discussion was initiated with the researcher question on how the teachers would do the webquest differently to address the challenges they encountered with the first try-outs (Lines 1a-b). This surfaced ideas from the teachers for new ways of organizing and designing their teaching and learning spaces and resources with more 'flexible timing and pacing' (ibid.) that could at the same time be embedded in their routine practices. For instance, the Lesson Teacher School B Mathematics ideas for "*choosing topics ahead*" for engaging students in research and presentation of a new topic *"using ICT and non-ICT resources"* (Lines 2a-g) and the Lesson Teacher School A Mathematics ideas for trying out different task group strategies to enable *"a multitude of solutions"* for more dynamic learning (Lines 3a–e). This provoked other teacher reflections on issues of conceptual and physical space to 'fit' the new approaches into their daily practice, as in: the teacher challenges *"to be a bit innovative"* in exploring a *"multitude of ways"* for solving time and timetabling issues (Lesson Teacher School B Mathematics, Lines 4a–e) and the teacher predictions of the physical efficiencies to *"narrow down on the time that will be wasted"* through technology enhanced student involvement in webquest presentations (Lesson Teacher School B English, Lines 5a-b).

Table XXIV - Seeding New Design Frames for STEM 21st Century Teaching and Learning

Focus Group Discussion Transcript		Design Turn Process	Knowledge Deepening Process
1.	**Researcher**		
a)	What are your final observations on this approach [project-based learning - webquest]?	Analysis – clarify new practice	New TPK (Refine)
b)	If you were to do it [project-based learning] again, what would you do differently?	Analysis – clarify new practice	New TPK (Refine)
2.	**Lesson Teacher School B – Mathematics Teacher**		
a)	On my part, I think if the method is to be effective … and because there is that issue of time.	Analysis – identify problems with new practice	New TPK (Refine)
b)	The next I have to use it, I will not use it on the topic I am teaching currently.	Design– propose new practice	New PCK
c)	So I make sure I choose a topic ahead.		
d)	So the students can research, can have enough time to research and prepare adequately in advance		
e)	So if I choose such kind of topic…		
f)	Then when they ?? did come to presentation they will be ready with the material -		
g)	So the issue of time - they will have enough material, they will have organized the mode of presentation - ICT as well as non ICT -	Design – propose new practice	New and Traditional TPK
h)	And I think in so doing the kind of presentation will be better than the way it was		
3.	**Lesson Teacher School A – Mathematics Teacher**		
a)	That single point that was arising [during the teacher observations of the Mathematics webquest]	Analysis – identify problems with new practice	New TTK (gap)
b)	That actually giving different tasks [to groups]	Analysis – predict outcomes of new practice	New TPK
c)	Would of course give us a multitude of solutions you are going to able to get		
d)	Rather than have the repetition in the presentation [all groups presenting solutions to same webquest task].		
e)	You have students presenting something entirely ne		
4.	**Lesson Teacher School B – Mathematics Teachers**		

Focus Group Discussion Transcript	Design Turn Process	Knowledge Deepening Process
a) Then again still on the issue of time.	Analysis – clarify problem with new practice	New TPK
b) I think eh we can also be a bit innovative on our timetable - em… rather than have a single lesson, doing presentation,	Development – create new practice	New PCK
c) I can combine an intermediate lesson, and push one of my lesson and combine with another lesson,		
d) So that I can have another period so they (the students) are able to continue to do the presentation		
e) There are a multitude of ways that we can solve the time issue.	Analysis – clarify opportunities in new practice	New PCK
5. Lesson Teacher School B – English Teacher		
a) The students themselves will be able to present using power point and eh and such	Analysis – predict outcomes of new practice	New TPK
b) And therefore I think we will be able to narrow down on the time being wasted…		

The teachers' ideas would seem to present a consolidation of their design thinking explored in conversations in chapters four and five. The difference in the final dialogue would appear to be the level of teacher preparedness to adapt and adopt practical design solutions that would gradually enable them to shift into the dimensions of co-teaching and co-learning described in the previous section. In Table XXV the School B English Lesson Teacher's response to the researcher's question on clarifying webquest in their practice (Lines 6a-c), would seem to encapsulate a new pedagogy design frame for *"starting small"* to *"connect learning"* to curriculum coverage and yet *"use more time outside class"* than *"the lesson time we are used to"* in a *"flipped classroom"* model that would also address their student learning needs to *"improve other skills"* [technology skills] rather than *"traditional skills"* (Lines 7a-m).[29]

Table XXV- Adapting New Design Frames for STEM 21st Century Teaching and Learning

Focus Group Discussion Transcript	Design Turn Process	Knowledge Deepening Process
6. Researcher		
a) So [are you saying] it's about being creative and innovative?	Analysis – clarify affordances in new practice	New PCK
b) Creating enabling conditions at class room level?	Analysis – clarify affordances in new practice	New TPK
c) As well [being] more flexible with this [webquest] approach?		
7. Lesson Teacher School B – English Teacher		
a) Let starts small	Design – conceptualize new practice	New PCK

[29] The flipped classroom is described by Educause (2012) as a pedagogical model in which the typical lecture and homework elements of a course are reversed. In the teacher discussions their design ideas for the 'flipped classroom' centred on student research on topics supported by the school computer laboratory and internet facilities outside the classroom in advance of the teacher introduction of topics.

Focus Group Discussion Transcript	Design Turn Process	Knowledge Deepening Process
b) So that they are able to connect learning – that their skills that they learning, they are still covering the curriculum -	Analysis – clarify current practice	PCK
c) Yet going a step further and assisting the community	Design – conceptualize new practice	New PCK
d) Em, time, of course, time, time,	Analysis – clarify problems with practice	PCK
e) Maybe a solution would be – we look at something we have to do in the middle of the term	Design – conceptualize new practice	New PCK
f) We begin earlier on that -so that they are able to use the 'flipped class' that we are talking about the other day	Design – conceptualize new practice	New TPK (refine)
g) We can use more time outside the class rather,	Analysis – justify new practice	New TPK (refine)
h) Rather than spend on lesson time which you would use to,	Analysis – justify new practice	New TPK (refine)
i) Because we must complete the syllabus, and there is great pressure in which we must do that.	Analysis – identify problems with current practice	PCK
j) Like Teacher X [Mathematics Teacher 2] is saying, we could use more technology so that we let like girls are able to print it their reports,	Design –adapt new practice	New TPK
k) They are able to type…	Analysis – justify new practice	New TPK (refine)
l) They really like that, they were jostling at the computers, each one wants to type,		
m) There were those who have never touched a computer, there were those who are learning about the computer, so we could improve that more –		
n) It would get them to improve on other skills, rather than the traditional skills		
a) I think it is a plus	Analysis – confirm affordance in new practice	New TPK (affordances)

Source: Focus Group Discussion Transcript, Mathematics and English project-based lessons, Schools A and B, February 2015

The teacher 'talk back' mappings appear to have captured a tentative model for building 'future appropriate signature pedagogy practices' (Passey, 2014, p5). More emphatically the 'design turns' and knowledge building processes present a teacher communal explication of their tacit knowledge, know-how and ideas about how to engage with the future model of teaching and learning within the affordances of their school facilities. The teacher design discourse would reflect Paavola *et al's.* (2004) contention in the literature that the 'hunches, insights and ideals' (p571) inherent in teachers' tacit knowledge can form the basis for innovative practices when 'explicated for communal and organizational' use (p570). Moreno (2005) on the other hand argued that this form of tacit knowledge or teacher's know-how is 'seldom documented' and 'made explicit' (p10) in teacher development models. Here O'Sullivan (2005) laments the lack of 'access and use of classroom based data' emanating from teacher lesson observation and reflection processes to understand the 'classroots realities' in which teachers work and as a basis for a 'useful needs assessment' to determine 'appropriate training content' (pp304 - 305).

Thus, a second key finding pointed to knowledge management and utilization of practitioner collective and continual conversations as a basis for professional learning. As Kenya enters a new phase of education reform for a 21st century learning curriculum and mass deployments of new technology in schools, the critical call is for new mind-sets in professional development and educational delivery models (Wanzala, Daily Nation, March 31, 2016). It may require new models for professional development and organizational learning 'less focused on information and more on knowledge management' (Hannay *et al.*, 2013, p77) that is based on shared vision for action and the cultivation of multiple professional conversations (Cowan, 2015) to explicate the change at every system level.

In this regard the head teacher narratives that were the starting point of the findings chapters illustrated some bold visions for action in ICT integration. The visions, however, presented contradictions and tensions in 'knowledge flows' (Hannay *et al.*, 2013, p74) between government and school visions, between techno-centric and learning-centric visions, and between defining new ways for achieving vision and documenting these.

> *National Vision:* There has been an effort by the Kenya government to enhance the use of ICT in the schools – with the government giving some schools computers
>
> Head Teacher 2, Interview, School B, September 2014

> *School Vision:* So we are going out of our way not waiting for the government to give us anything but eh we have done a deliberate allocation as a school for the equipment that we are buying.
>
> Head Teacher 1, Interview, School A, September 2014

> *Technical Vision:* Luckily we have ICT programs in the strategic plan. It is not only in paper, because the school has three laptops, two projectors fifteen desktops in the computer lab and Wi-Fi.
>
> Head Teacher 3, Interview, School C, September 2014

> *New Ways for Achieving Visions:* The vision may not have really changed as such [since the SIPSE intervention], but what has changed is that oh we can achieve this vision in a different way, a way from what we have always thought, maybe there is a better way, another way in which we can achieve our vision.
>
> Head Teacher 2, End of Project Interview, School B, February 2016

> *Documented Vision:* Yes we have a policy or ICT; in fact we have got it printed out. The whole idea is to make sure those students and the teachers embrace the use of ICT, because that's the way to go.
>
> Head Teacher 4, Interview, School D, September 2014

Only one out of the four research schools had documented their school ICT vision and policy – while all of the schools had integrated investment in ICT equipment in school strategic planning. This is a phenomenon echoed in the literature where a survey of ICT policy and implementation in secondary schools in Kenya conducted by Murithi *et al.* (2013), revealed some 90% of schools lacking their own developed ICT policy, vision and mission statements. The authors note how school inability to develop ICT policy to determine their own priorities was 'creating dependence' (p202) on Ministry of Education guidelines that was contrary to the political agenda of 'decentralized approaches' for finding solutions where 'centralized ICT policies are inadequate' (p197).

The third key finding elucidated tensions between national and school vision and action that appeared to limit teacher spaces for innovative practices and risk taking and reforms linked to national ICT policy advocacy for innovative practices. The following head teacher and teacher narratives showed dissonances between centralized and school level management and teacher understandings on performance measures for *"assessing"* teacher ICT enhanced practices that contrasted opportunities and constraints between *"old and new ways"*, *"innovativeness and creativity"* and *"risks"* of innovation *"going down the drain"*.

> We are working under the Ministry of Education, and you find that as a country *they have not changed from the old when they come to assess us,* they want to see the paper work, if it is schemes of work, they will not accept digital, because in the digital they will tell you that maybe you have duplicated it from somewhere, so that one, it becomes a challenge when we are using ICT.
>
> Teacher Observer 3, Science Problem-based Learning Lessons, Focus Group Discussion, School C, September 2014

> Yes – we have signed a performance contract with our employer the Teacher Service Commission…, one of the areas that is being looked at is *innovativeness and creativity* – how creative and how innovative was the teacher during the teaching and learning process, and eh, em, that is where ICT comes in, ah, there is a part on that, and eh, I am sure that will make the teachers to be a bit keen.
>
> Head Teacher 2, End of Project Interview, School B, February 2016

> The performance contracts, you've heard about them, and the appraisals…, the principals have already signed a performance contract, and they are being told how we are going to sign with them the principals about how we are going to go about doing our things, the pressure will pile even more, I assure you, so, the *risk of the gains that have come about because of SIPSE, of going down the drain is even much more*, than it was before the performance contracts and appraisals came.
>
> Teacher 1 English, End of Project Interview, School B, February 2016

In the literature, Sachs (2005) confirms a double bind in national dialogues about 'measuring teacher performance or improving teaching through a development approach' (p2). Hannay *et al*. (2013) speak of the need for 'safe opportunities' (p72) to enable teacher professional development conversations that can protect the kind of risk taking and innovative thinking that evolved in the SIPSE intervention and challenge teacher and school organization tacit knowledge and established ways of *"doing our things"* (Teacher 1 English).

The fourth key finding suggested that continuity in teacher professional learning beyond interventions like SIPSE requires a broader engagement of dialogue and knowledge flows to support educational learning ecosystems for 21st century learning schools and societies. The evidence in the participant narratives of dialogue continuity beyond SIPSE was tentative. The following head teacher and teacher discourses elucidated contrasting themes of school isolation, teacher community learning, district networking and national teaching disruption as school communities struggled during and after SIPSE to embed agendas for ICT integration in school practice.

> *School isolation:* I think all schools work in isolation … and basically it's because we do not have a national policy of integration of ICT in our schools…, so because there is no policy schools will always allow for the leadership of the principal to draw the agenda of ICT for the school. So it is difficult to say that we work together.
>
> Head Teacher 1, Interview, School A, September 2014

> *Teacher community learning:* In terms of use of ICT facilities [we rely] on the SIPSE teachers… They have key role in passing all the same information [from the SIPSE course] to the rest of the teachers in the school
>
> Head teacher 4, Interview, School D, September 2014

> *District Community Learning:*
> T2: Within the school we collaborate, but eh with other schools we eh…[pause]
> T5: Within the district there is a programme that has been run for some time CEMEASTEA[30] and slowly they have been trying to integrate ICT in teaching and learning
>
> Teachers 2 and 5, Science Problem-based Learning Lesson, Focus Group Discussion, School C, September 2014

> *Teaching disruption:* Let me be honest with you, last year was not a good year for teaching, for four months we were not able to be together because of the industrial [teachers' strike], so I tell people there was no school last year…, so I strongly feel we need to come together and just look at how is it going, just that… what is the way forward, how are you feeling, how are you helping one another, just that…
>
> Head Teacher, End of Project Interview, School B, February 2016

What is of interest are the final narratives from two of the teacher advocates of the 'flipped classroom' approach in the teacher design mapping. The narratives coming eight months after the end of the project highlighted the extent to which the teachers managed to embed their ideas within the affordances and 'boundaries' of their daily practices and their school and education system contexts.

> T2:
> …*on project-based learning:* For me I have been doing it. Most of the topics in Mathematics and with teams we have moved away from calling it a problem –it's a project eh…, now I have become more of a facilitator in my classes, you are a guide, you just give them the project...

> T1:
> …*on project-based learning:* I have not tried it for a while, I think it is because of the nature of my, my area of specialization, that I find that it doesn't fit very well (em, em)..., but I feel that mine

[30] CEMESTEA – Centre for Mathematics, Science, and Technology Education in Africa

> because of the level of interaction that we need with our students that other methods are better…, PowerPoint is very useful, I use that very often, group work, questioning, I like that much better...
>
> Teacher 2 Mathematics and Teacher 1 English, End of project interview, School B, February 2016

The teacher narratives illustrate a progression of teacher professional learning and knowledge creation to find solutions appropriate to their learner needs. The teacher design solutions would moreover seem to have pushed 'the boundaries' of their routine practice towards more innovative models for student involvement, thinking forward and active teaching and learning. However, the following Teacher 2 reflection was pertinent in identifying an essential 'gap' in the SIPSE intervention. The teacher narrative would suggest a need to re-conceptualize the model as a 'continuous process' of responding to day-to-day needs of teachers and learners within broader frames of the education system.

> SIPSE has taken us so far. The SIPSE teachers. But then there is a gap somewhere, for me I see a gap. Ah, for me SIPSE should be a continuous process. SIPSE should be a… It should be tailored to the needs, the day to day needs in our education system.
>
> What I mean is this, now that the teachers have learned, I don't know if it is around 6 teachers per school, [who have] gone through SIPSE, if we are to have the correct impact and turn things around, SIPSE has to play a role, a bigger role than what it has so far done, in this manner, according to me, now after training, we should get to material production, that one will bring on board more people, we are how many schools from Kenya…
>
> Teacher 2 Mathematics, End of Project Interview, School B, February 2016

There is nothing new in the teacher suggestion for creating teacher design teams to continue the work beyond SIPSE in materials production. What is radical may be the implications for teacher transformed practice and learning from solitary implementers of signature pedagogies to teacher multi-disciplinary teams designing, problem solving and trying out new ideas and frames for materials development. From the literature O'Sullivan (2005) points out 'the pivotal role of classroom processes' as a 'centre-stage' for tailoring professional learning to the *"day to day"* needs of teachers discussed by Teacher 2. More specifically the author contends the need for 'taking lessons from the successes' (versus failures) of reforms and interventions, 'even if they are limited and small-scale success stories' (p301) - as illustrated in the small-scale successes of teacher changing classroom practices throughout the SIPSE professional learning. In this regard Hannay *et al.* (2013) defend a broader knowledge management that emanates from the workplace (classrooms, schools, districts) for 'organizational learning'. The authors propose a need to outline a 'framework for action towards a shared vision' for 'directing the content of social learning' (p66) among teachers within and across schools and districts as in Teacher 2's vision for professional learning beyond SIPSE.

In summary, in this theme there was evidence of teacher collective design of a tentative future pedagogy responsive to the 21st century learning needs of their students. Of particular note in the findings was the trajectory of teacher design thinking for seeding, negotiating and adapting solutions for more flexible teaching models that could be innovative and at the same time be embedded in their routine practices. The findings highlighted a tentative model emerging from the teacher design frames that suggested knowledge management and collective and continual conversations as a basis for professional learning.

The findings illuminated disconnects in knowledge management and flows between government and school visions that seemed to create further disconnects in clarifying and documenting the object of ICT integration that was the starting point of the findings chapters. The evidence pointed to a need for and value of broader models for organizational learning that are based on shared vision for action to explicate and build communal understanding for change and reform at every system level.

6.3 Capturing Teacher Technology Pedagogy Knowledge through the TPACKtivity Lens

The TPACKtivity lens as presented in Figure 6.1 illustrates an activity system of teacher TPK applications that represents both the end and new beginning of the teachers' professional learning journey. What is significant is the tentative change in the 'object' of ICT use at the end point of the SIPSE intervention. The object has moved towards activities for deeper student involvement and engagement in learning that puts a new emphasis on 21st century skills as well as the emphasis on academic knowledge and performance that was present at the mid-point of the intervention.

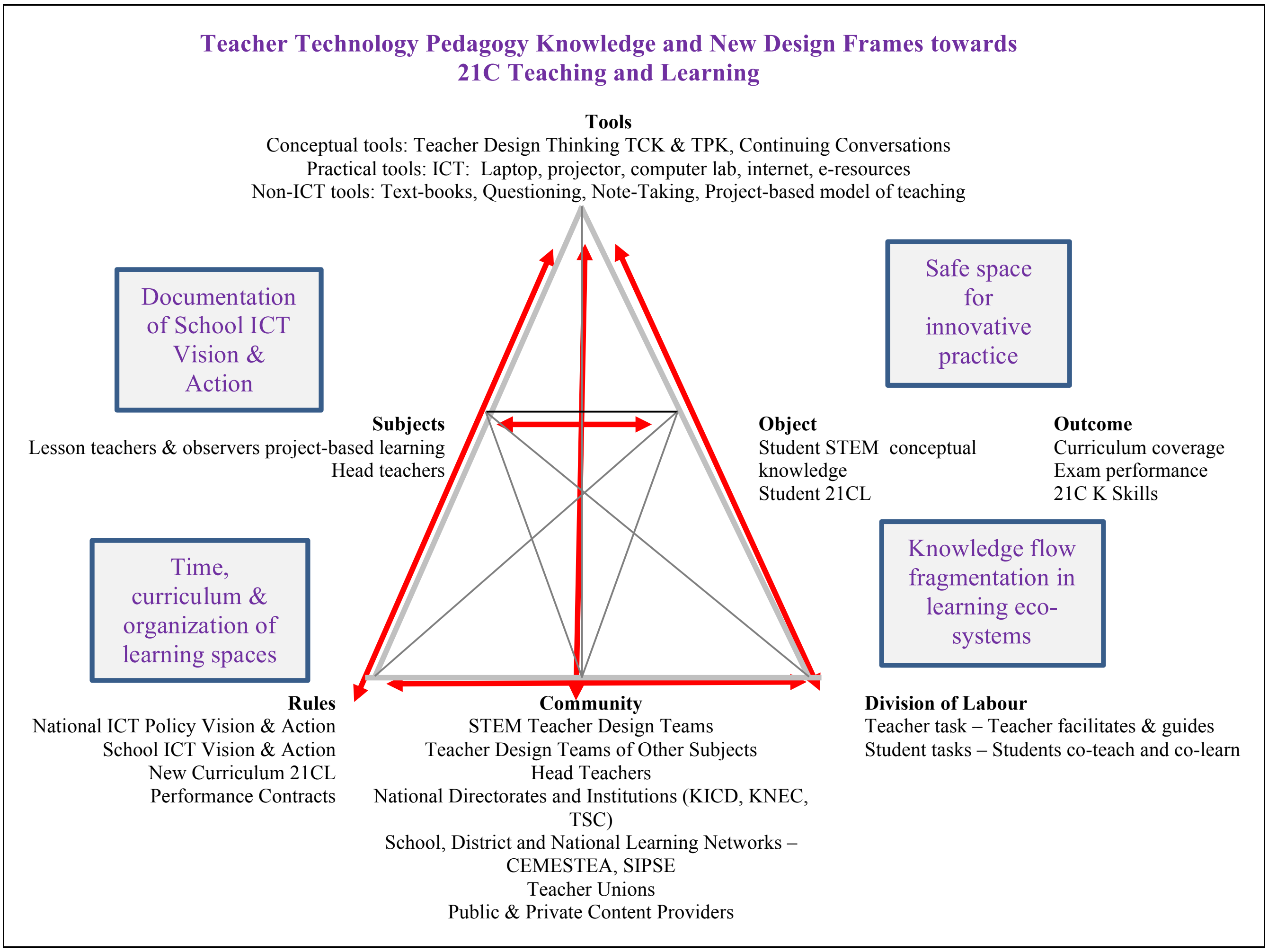


Figure 6.1 - TPACKtivity Mapping of Teacher TPK Applications (Adapted: Terpstra, 2015)

The key tensions, contradictions and learning opportunities were four, and they centred on: disconnects between national and school level vision and action planning for technology integration; recurring themes of time, curriculum and the organization of learning spaces that challenged teachers in their exploration and design of technology use for innovative practice in STEM teaching; dissonances in knowledge flows between teachers and the extended community of school, district and national learning eco-system to explicate collective understanding for technology integration solutions that challenge tacit understandings and traditional ways of doing things; safe spaces for enabling teacher innovative practices amid new requirements for school performance and appraisal.

The final chapter of summary, evaluation and conclusion will consolidate the findings in relation to each of the three research questions - with a focus on how the research findings from the SIPSE ICT-CFT-TPACK-in-practice intervention can inform models for future teacher professional development in relation to ICT integration in classroom practice.

CHAPTER 7

Conclusions

7.0 Introduction

In this chapter a summary will be presented of the findings and contributions to the field of ICT and teacher professional development emanating from the research. The study aim was to appraise the intervention model design for teacher professional development in the use of ICT in classroom practice as associated with the Strengthening Innovation and Practice in Secondary Education (SIPSE) project over its two cycle pilot phase. The objectives were to track the object of ICT use in school and classroom practice as perceived by school head teachers and teachers throughout the intervention; to investigate the characteristics of teacher design for ICT use in STEM as evidenced in their approaches to problem- and project-based learning activities at the mid and end points of the SIPSE intervention. The research was conducted using a design-based research methodology incorporating the three lenses of Activity Theory (AT), Technology Pedagogy and Content Knowledge (TPACK) and ICT Competency Framework for Teachers (ICT-CFT) to assist in the appraisal of the SIPSE intervention.

The chapter commences by outlining key findings in relation to each of the research questions. A discussion is presented on each question's key findings thereafter. In this regard, the discussion revolves around a deeper analysis of the findings with connections to the salient literature presented in chapter two. This is followed by key conclusions drawn from the study which include: the study contribution and insights to the field of teacher professional development for ICT use to improve and innovate practice; implications for the design and research of future models of professional development for ICT use; research limitations in relation to constraints of the research study design and context; and a final reflection.

7.1 Findings and Discussion

7.1.1 Addressing Research Question 1: The Object of ICT Use in Teaching Learning

> *Most Significant Change Story - A shift towards technology integration in practice…*
>
> I think *for the first time I have teachers who come to sign for the use of the projector and the laptops* - where the laptop and the projector were only used for meetings… So it might be that there is a great impact, we may not be able to see it well where we are, *but there is a shift in how we do things that is a result of the SIPSE programme*
>
> Head Teacher 1, Interview, School A, September 2014

Key Findings 1

As presented in chapter four, the head teacher and teachers who took part in this study viewed the object of ICT integration in teaching and learning from several perspectives that were reflective of multiple and often competing national educational reform policies and directives. The findings show participant perceptions that were situated firstly in the 'historical-cultural' object of teaching and learning where agendas for academic excellence and school performance in national examinations vied for attention with child-centred, learner-friendly, life skills and inclusion policies among others. In these settings, the findings highlight patterns of pragmatism over idealism in participant perceptions. For head teachers, the object was centred on school examination performance and the 'push' for student placements in tertiary institutions. The findings show similar patterns in teacher narratives placing emphasis on school 'academic knowledge' while their commentary for involving students actively in their learning presented a contrasting 'pull' dimension to the discourse.

The push and pull dichotomy in key findings 1 echoes views discussed in the literature on education system challenges to integrate and evaluate broader life skill competencies integral to reform programmes – in particular competencies emerging in the 21st century skills literature (Voogt & Roblin, 2010, 2012, Butler *et al.*, 2013). Into this lacuna the findings highlight participant perceptions on the object of ICT integration as having potential to advance reform agendas for inclusive, quality, learner-friendly environments. The findings point to some evidence of head teacher and teacher beliefs in the affordances of the technology tool in itself for realizing change and transforming practice – in parallel with literature assumptions on the role of technology to 'impact positively on student performance and heighten student innovation' (McDonough & Le Baron, 2010, p21). This may explain the finding that shows dissonance in teacher reflections on what constitutes the role of the *teacher* and *good teaching* in the educational push and pull currents towards new technology and learner-centred paradigms. It is a conceptual gap that was discussed in chapter two where Livingstone *et al.*(2012) note the irony of an information age where much attention has been given to student learning, yet so little is known about the learning processes of 'teacher knowledge workers' (p1).

The findings show further gaps between participant *perceptions* and *applications* of technology in practice. Whilst head teacher narratives described ideal technology use scenarios for *improving* and *transforming practice*, teacher actual applications of ICT and technology knowledge (ICT-TK) were centred on less sophisticated tool use for *supporting existing practice* in STEM subject teaching. The applications were not dissimilar to tool usage patterns reported in the literature which suggest that most teachers struggle to integrate high quality digital learning tools (Boschman *et al.,* 2016) and turn to more accessible tools such as presentation software to support their existing practices (Trucano, 2005; Harris, 2008; Sanchez & Salinas, 2008). More emphatically the findings point to teacher technology use as primarily influenced by their perceptions of tool affordances for fast tracking student conceptual understanding and reproduction learning in the examination oriented cultures of their school and education system environments. The findings further show evidence of teachers situating the locus of technology control that excluded student access.

Yet data from mappings of teacher post-lesson observation 'talk-back' (Koh *et al.,* 2015a, p88), presented a microscopic view of teacher design ideas for more sophisticated usage of the computer laboratory and mobile technology to enable student access inside and outside of the classroom. The design solutions presented both elementary and radical perspectives that challenged 'historical-cultural' belief systems associated with the computer laboratory as a specialist zone for technical skills development and mobile technology as a banned device in school activities. The findings would reflect an emerging literature focus on teacher perceptions of the affordances inherent in environmental opportunities and limitations which may offer more nuanced potential for change than teachers' take-up of technology *per se* (Hammond, 2013; Power *et al*., 2014). In other words, the challenges of access to technology in the under-resourced e-environments of the research schools prompted teacher design ideas for exploring innovative solutions. On the other hand, as discussed by Passey (2010) in the literature, the scope for teacher implementation of their design solutions seemed to be more profoundly influenced by political, cultural and social agendas of school and education system environments than by linear approaches (as inherent in the SIPSE intervention design) for teacher capacity building towards more sophisticated technology integration.

In summary and in response to research question 1, the evidence suggests teacher and head teacher perceptions of the object of ICT integration as primarily for enhancing existing practice but with aspirations for exploring innovative practice. The evidence further highlights complexities for tracking the object of ICT integration in linear interventions like the SIPSE phased programme cycles of *technology literacy* and *knowledge deepening* of teacher professional development – where wider cultural, social, political and environmental factors can influence teacher decision making and technology take-up in a non-linear way.

7.1.2 Addressing Research Question 2: Teacher design for ICT use in STEM teaching and learning mid-way through the SIPSE pilot programme as evidenced in problem-based lessons

Most Significant Change Story: A new source of information…

I think for me it has em, it has opened a new, a new way of… sourcing, sourcing for information, because of outsourcing for the correct information, em, and also presentation of the same

Teacher Observer 2, Focus Group Discussion, School A, September, 2014

Key Findings 2

As explored in chapter five, interpretation of data from teacher problem-based lesson planning and try-outs mid-way through the SIPSE pilot programme, shows evidence of teacher application of technology content knowledge (TCK) in usage and re-purposing of digital resources and tools such as presentation, concept mapping, video and internet for dynamic representation of content and concepts in language, mathematics and science topics.

The findings, however, show issues emerging from data trends across teacher narratives, lesson plans and observation notes that suggest an over-emphasis on what Blanchard, Harris and Hofer (2011) describe in the literature as *conceptual knowledge building* and under-emphasis on *knowledge expression* activity types in the teacher lesson repertoire.

The key findings may be explained by evidences in teacher narratives pointing to a 'fear factor' barrier related to the historical and cultural practices of knowledge transfer activity types that teachers have established in their traditional toolkit of classroom practices for dealing with the pressures of examination-oriented secondary school cultures. As corroborated in the literature by Ang'ondi (2013) teachers in the Kenya classroom 'would not want to mess with the status quo, thus they would rather do things the way they have been used to' (p25). In this regard the findings portray particularly potent elements of teacher perceived new technology interference and disruption of traditional tool use and ways of doing things. Digital content was highlighted in teacher narratives in almost equal measure in terms of opportunities (ease of accessibility and availability from national institutions, the internet, providers) and challenges (digital content saturation and challenges therein in identifying culturally appropriate digital content that is aligned to curriculum objectives and teacher knowledge of local contextual and learner needs). These issues are mirrored in literature discussions where McDonough and Le Baron (2010) and Padilha (2013) relate on the greater complexities of ensuring the quality of educational resources and content relevance in the emerging digital environments of school cultures. On the other hand, evidence from case studies in the literature such as the DEEP research (Leach *et al.*, 2006) shows that when educational technology and teacher professional development are combined with supportive curriculum materials it can lead to significant change in teacher practice and student learning activities. Jaipal-Jamani and Figg (2015) advocate building teacher content knowledge around a 'repertoire of technology-enhanced activity types that are appropriate to teach the content' (p144). These arguments suggest more use of exemplary materials and activity types as models for teachers to navigate through the complexities of digital content saturation.

The findings threw up further imbalances in teacher discourse around traditional mediation tools of student note-taking, teacher note-giving and questioning techniques to the detriment of new technology mediation tool discussions. Expected themes on technology use to support student deeper conceptual understanding and application in problem-solving scenarios at the core of the *knowledge deepening* cycle of the programme intervention, did not materialize in the teacher narratives. On the contrary, the findings evidenced general trends in the teacher reflections to subsume discussion on technology affordances under broader frames of pedagogical and content discourse about STEM teaching and learning. In the literature Hofer and Harris (2012) explicate the trends in relation to experienced teacher tendencies to include educational uses of technology as part of their curriculum pedagogical discourse. In this regard the microscopic view of the teacher 'talk-back' mappings shows evidence of 'cognitive dissonances' in teacher perspectives on the very nature of STEM content knowledge as a fixed (factual and procedural) or dynamic (conceptual understanding and use) entity. The teacher debate reverberates with critical discourses in the literature on learner achievement in STEM subjects based on international benchmarks, where Akyeampong (2016) describes trends in African student Mathematics and Science performance as limited to basic 'factual and procedural knowledge' with weak acquisition of higher order 'conceptual and transformative skills' (p5). However, other findings from 'talk back' narratives highlight 'disruptive benefits' of technology integration in facilitating shifts in teacher group cognition and emerging capacities for thinking strategically and differently about STEM subject content. The data shows evidence of teacher incipient design ideas that challenged their tacit understandings to move beyond the 'factual and procedural' activity types embedded in their STEM routine didactic practices. The findings echo literature discourse on the significance of ICT as a new 'epistemic tool' (Koh *et al.*, 2015, p459) to support teacher critical thinking and exploration on 'other epistemological and perceptual possibilities for knowledge construction' (Padilha, 2013, p235).

Yet the findings also suggest weaknesses in the programme design that relies on teacher community reflection dynamics as key to change. It is an issue echoed in the literature where Boschman *et al.*

(2016), point to outside expertise as 'commonly needed' to support design interactions (p4); while Koh *et al.,* (2015a) argue advantage in both teacher independent design and teacher co-design with researcher or expert outsiders to enable 'epistemic leaps' (p104) beyond the routine hold of existing practices. In this regard the role and influence of the outside researcher in the teacher 'talk back' conversations may be significant while the researcher was cognizant of their 'positionality' (Bourke, 2014) in relation to unduly influencing teacher navigation of dissonances created by the technology disruption.

Finally, and in regard to this question, the evidence shows characteristics of teacher design of ICT in problem-based learning to be at a *technology literacy* level for supporting existing practices of STEM factual and procedural knowledge building activity types. Yet, as in the findings for research question 1, there is evidence of teacher design ideas in transition towards a *knowledge deepening* level for exploring more innovative STEM knowledge expression activity types in their lessons. The evidence suggests professional learning at the mid-way point as incorporating linear and non-linear elements in its dependence on the quality of teacher design team interaction, internal and external support and the depth of the problem space of technology disruption to evoke conditions for significant interrogation of and leaps beyond routine practices.

7.1.3 Addressing Research Question 3: Teacher design for ICT use in STEM teaching and learning at the end of the SIPSE pilot programme, as evidenced in their approach to project-based activities

> *Most Significant Change Story: An emerging professional learning community…*
> What is the impact [of SIPSE]? The impact was that eh, teaching of science became more interesting, in the sense that the students were able to relate to what was been shown through the projector. Who was affected? Definitely the students got a very big effect and the *other people who got affected are the teachers…* because those who were not part of the project…, they also learned the use of the computer, the use of laptops and even getting lessons in their individual subject areas.

Head Teacher 4, Interview, School D, September 2014

Key Findings 3

As presented in chapter six, the findings show evidence of teacher application of technology pedagogy knowledge (TPK) at the end of the SIPSE pilot programme intervention that introduced 'knowledge sharing' models of teaching for deeper student engagement in 'webquest' project-based lesson activities. Interpretation of the data shows an incipient shift in teacher understanding of the student use of webquest as a cognitive tool for a more active role in co-construction of knowledge and co-development of solutions to problem tasks. The findings show an emergent student voice in the data sets that seemed to have a powerful effect in enhancing teacher positivity towards twenty first century learning and skills development for problem solving, information literacy and collaboration – skills critical for the transformation shift in national and regional development as highlighted by Akyeampong (2016).

However, and notwithstanding the apparent evidence of teacher recognition of the potential of more symmetric teacher-student relations for co-teaching and co-learning in project-based lessons, the findings show teachers locked into recurring issues of time and curriculum coverage, classroom organization and performance demands that seemed to continually counteract professional community exploration of new tools and innovative approaches even at the end of the programme intervention.

The literature echoes the key finding tensions and contradictions where despite teacher agreement on the importance of more active learning pedagogies, usage is not widespread (O'Sullivan, 2005; Eison, 2010; Hinostroza *et al.,* 2011; Asia Society, 2015; Akyeampong, 2016), and despite mass investments for access to new technology tools in schools and classrooms, the anticipated transformational innovation that pushes education beyond conventional practices has not been realized (Cuban, 2002; McDonough & Le Baron, 2010; Koh *et al.,* 2015b); and despite reform movements for 21st century learning integration in curriculum, positioning it within the existing curriculum is 'perhaps one of the more complex and controversial issues of its implementation' (Voogt & Roblin, 2010, pi).

Yet interpretation of the data from teacher post-project lesson observation 'talk-back' shows some evidence of collective teacher design ideas for a tentative future pedagogy responsive to the 21st century learning needs of their students. Of particular note in the final theme findings is teacher design thinking growth for seeding, negotiating and adapting solutions that have both radical and routine dimensions – such as group ideas for 'flipped classroom' enactments that could radically change the relationship in teacher and student roles for co-directing the learning space but that can be embedded in routine planning and activities for curriculum coverage that was a recurring teacher concern.

A key finding that was revealed through the research design TPACKtivity lens across the data sets shows a nuanced but significant shift in participant perceptions of and approaches to the object of ICT integration in teaching and learning over the two cycles. Interpretation of the data shows head teacher and teacher mid-programme perceptual awareness of ICT integration as a tool for enhancing student academic knowledge and learner-friendly schools, shifting towards teacher end-programme perceptual frames of ICT integration incorporating 21st century learning dimensions. The findings highlight teacher 'talk-back' (Koh *et al.,* 2015a, p88) design conversations as a key tool in the programme for teacher collective learning, explication of design ideas and creation of knowledge to address the ICT integration challenges - inclusive of challenging teachers' own existing tacit knowledge about STEM concepts and ways of teaching STEM for deeper student involvement and 21st century learning.

In this regard, the findings would seem to inform future models of teacher professional development for ICT use in classroom practice that embeds more emphatically a professional learning component for collective and continual teacher design conversations. It could be expressed as a *21C teaching and design thinking for ICT use in classrooms (21CT-DT-ICT)* component[31] - for building teacher collective design capacity, knowledge and ideas for ICT use that can be continually tested, reviewed and shared within and across the school teacher communities. The component echoes Cowan's (2015) discussion in the literature on 'co-construction of knowledge through effective conversations' (p2) and Hannay *et al's*. (2013) analysis of organizational knowledge management for fostering 'collective, constructive and conversational learning practices among teachers across districts' (p66). The findings showed a desire expressed in the participant narratives for such future formats of professional learning continuing beyond the SIPSE programme intervention in the schools. As such the findings would appear to consolidate what Power *et al.* (2014) describe as 'strong conceptual framing' in the design of a future model - with implications for creating school-based conditions for on-going professional development of teacher practice as a co-learning and co-design model for collaborative knowledge construction. Yet tensions identified through the TPACKtivity lens highlighted disconnects between national level vision and reform agendas and school level vision and action agendas for technology integration – where, for example, only one out of the four research schools had a documented ICT school policy.

In sum, and in response to research question 3, the evidence shows characteristics of teacher design for ICT use in project-based learning lessons at the end of the SIPSE intervention as tentatively at a knowledge deepening level. The characteristics highlight teacher design conversations and practice try-outs for embedding exploratory flipped classroom models of teaching – to engage students as co-teachers and co-learners and promote 21st century learning involving technology enhanced collaboration and problem-solving activities within and beyond the classroom. The findings would

[31] The component is an adaptation of the Koh *et al.* (2015b) *Design Thinking Framework for ICT Integrated Lessons to support 21 Century Learning* (21CL-ICT-DT) (p4)

appear to point to a need for embedding *twenty first century teaching and design thinking for ICT use in classrooms (21CT-DT-ICT)* encompassing collective and continual teacher design conversations as a core component in future models of professional learning that move beyond models of linear programme interventions.

7.2 Strengths and Limitations of the Study

The strengths of this study lie in the qualitative research-based design which integrated a unique 'TPACKtivity' lens to explicate the 'what' of the teacher professional learning (TPACK), and 'how' teachers learned within the context of the four research school settings (AT), and 'when' and 'how' teacher use of ICT started to change and develop during the two cycles of the SIPSE intervention (ICT-CFT). The lens offered insights into the issues, tensions and opportunities that emerged during the teacher professional development journey as they enacted technology use in STEM teaching and learning in the real and challenging contexts of their school and classroom settings.

There were at least three noteworthy limitations to this study, which included the research methodology, the positionality of the researcher and the sampling of the schools. First, the methodology conceptual framework converging the triple lenses of context (AT), practice (TPACK) and programme (ICT-CFT) may be viewed as a strength, but it is also a limitation due to the time required and complexity involved in multiple layers of analysis. There were also issues of prioritization of theme selection from the data narratives - for example, balancing theme selection from the end-of-project interview data sets involving three participants with theme selection from interview and FGD narratives involving twenty-eight participants. Inevitably there were dominant voices.

The second limitation that is common to qualitative research was the positionality of the researcher. Given her multiple roles in course design, tutoring support, evaluation and research in the SIPSE pilot project, the researcher was aware of the need to pay greater attention to issues of reflexivity and power relations. These could potentially have destabilized the tenuous nature of the dialectical relationship between the researcher and the head teacher and teacher participant groups throughout the research cycles.

Finally, on school sampling, there were four schools selected for the research from the twenty schools involved in the SIPSE pilot programme. The selection was based on a purposive sample defined by the researcher in relation to criteria of rural/urban and gender representation but mostly based on geographic convenience. Due to the logistics involved in carrying out the research over three field trips, the purposive sample was reduced to two urban schools from the original sample by the second trip. Even within the schools there were difficulties, sometimes insurmountable in arranging individual interviews, as discussed in chapter three. Given the focus of the research to examine the SIPSE model in context, the progressive reduction in school sampling over time necessarily reduced understanding of the model implementation in multiple school contexts and in particular in deep rural school contexts where there are particular challenges for technology and connectivity access.

While acknowledging these limitations, nonetheless it is argued that the study does have a contribution to make to our understanding of teacher development processes for the promotion of ICT integration in practice that it could inform future models and programmes in this regard. These will be examined in the following sections.

7.3 Implications and Recommendations for ICT-related Teacher Development

This study focused on an appraisal of the SIPSE model for teacher professional development for ICT use in classroom practice, conducted through an in-depth qualitative research approach, incorporating a convergence of three dynamic frameworks (ICT-CFT, TPACK, AT) from the field. As such the study presents a unique conceptual framework on the basis of which the findings offer, potentially, a knowledge contribution to future models of teacher professional development for ICT use in classroom practice. The findings as presented above to each of the research questions contribute to the discourse at two levels: practice and 21st century teaching and design thinking for ICT use; policy and ICT shared vision and action. Some of the findings support the on-going discussion in the literature. Other findings bring in new aspects that can add to the literature discourse and open areas for future research.

Key recommendations based on the findings are discussed below. The recommendations are organized in the learning system domains of the ICT-CFT framework that underpinned the SIPSE intervention design. They are focused on three potential constituencies of findings' implications for: 1) SIPSE programme co-planning and co-provision of professional development intervention for ICT use with partner countries; 2) policy makers at local, regional and national levels in relation to professional development interventions for ICT use; and 3) other providers and researchers in the field of professional development in relation to effective ICT integration in classroom and school practices.

Recommendations 1: Understanding ICT in Education (Policy)

The findings showed a picture of head teacher and teacher perceptual understanding of the object of ICT integration as centred on enhancing existing practice but with aspirations for exploring innovative practice. A key finding highlighted a need to rationalise national agendas for teaching, learning and assessment so that they do not create the contradictions and tensions evident in the research school and classroom practices for ICT integration – while the literature highlighted the complex and challenging difficulties that would be involved. Policy tensions at a local level were manifested in a lack of shared policy vision and action planning for ICT integration where only one school had a documented ICT policy. Practice tensions were manifested in teacher continuing concerns about time, curriculum coverage, classroom organisation and performance demands.

The study therefore recommends that at *SIPSE programme design level* there is a need to strengthen and build on partnerships with Ministries of Education and national expert working groups (with representation from ICT departments, curriculum, teacher development and teacher services institutions and universities) as co-drivers and co-partners in programme development, implementation and evaluation. The focus should be on using the intervention as an opportunity for continuous monitoring, evaluation and learning and awareness raising on the issues and the success stories emanating from the SIPSE intervention locale of ICT use in STEM classroom practices so as to inform policy reform agendas and promote institutionalization of emerging good practices appropriate to school contexts.

The recommendation at *policy level* calls for strengthening ICT policy articulation and capacity building from macro (Ministry of Education, Teacher Education Department, Curriculum, Teacher Service Commission), to meso (Teacher Education Institutions, Pre and In-service) to micro (County Directorates, School Management) levels to connect system-wide vision and action planning for ICT integration. At the heart of the alignment should be knowledge management focused on fostering 'collective, constructive and conversational learning practices' (Hannay *et al*., 2013, p66) centred on ICT integration in classroom practice as a basis for negotiating visions and action for reforming and transforming practice.

At levels of *providers and researchers in the field of professional development for ICT use* the recommendation is to consider a need to support action oriented design-based research focused on the classroom and the classroom processes of teaching and learning with and through ICT as centre stage. This may have implications for research design to take into account the complexity of the 'teaching and learning ecology' in the broader 'context' (Nicopoulou & Cole, 2010, p70) of classroom practice influences (teacher routine practices, beliefs about teaching and learning, national and school level education goals, experiences of working with other people in the school community). It may require research design considerations beyond the once off 'implementation' focus on what works and does not work, to embrace the need for continuing research processes over many iterations. The requirement is for deeper understanding of how even small-scale incipient change and successes can contribute to broader reform and newform agendas for professional learning programmes.

Recommendations 2: Curriculum

The findings presented teacher dynamic application of technology content knowledge (TCK) in usage and re-purposing of digital resources and tools for dynamic representation of content and concepts in language, mathematics and science topics. Teachers, however, showed an over-emphasis on conceptual knowledge building and under-emphasis on knowledge expression in technology enhanced classroom activity try-outs. While teachers explored affordances of the internet and e-content developed by national curriculum bodies to supplement and enrich traditional textbook content, there were concerns about digital content saturation. There were problems with the identification of culturally appropriate digital content aligned to curriculum objectives. Towards the end of the programme intervention, there was some evidence of a movement toward 21st century learning dimensions, while teachers expressed some doubt about whether this could be sustained.

The recommendation at *SIPSE programme design level* is for strengthening the capacity of collaborative design teams of teachers, teacher educators and curriculum experts to develop exemplary curriculum materials of technology enhanced STEM lessons. More specifically, the need is to enhance platforms for showcasing teacher design materials of technology enhanced STEM lessons and resources across schools, regions and countries that can address the dual challenges of culturally appropriate materials and curriculum coverage in the examination oriented cultures of secondary schools. The focus should be to create a platform of teacher and expert design exemplary curriculum materials reflecting different levels of technology use to model knowledge transfer and knowledge sharing deepening approaches for building 21st century learning classrooms.

At *policy level* there is an opportunity in the movement towards new curriculum reform and transform for focusing on higher order STEM 21st century skills for 'interpreting, analysing and manipulating data' (Okyeampong, 2016, p7) to better prepare students for the new and fast changing world of work in digital societies. The recommendation is for national systems to use interventions like SIPSE to examine the value add of ICT integration in addressing the coherence challenges between curriculum reform intentions, classroom implementation and assessment of student learning outcomes to apply STEM 21st century concepts and skills for solving routine and complex real-world problems.

At *researcher and professional development providers level* the recommendation is for programme and research based design that is more focused on the enactment and assessment of curriculum reform in the centre stage of classroom practice. A particular need and recommendation is for the co-participation and empowerment of schools communities (head teachers, department heads, teachers) in research design of alternative methods for formative and summative assessments of STEM 21st century skills and in utilizing technology to support data analysis by school communities for informing, improving and sustaining innovative teaching practices, relevant learning and improved outcomes.

Recommendations 3: Pedagogy

The findings showed an uncertainty about the role of the teacher and good teaching in relation to the effective integration of ICT into classroom and school practice. The use of ICT tended to be primarily teacher-directed rather than student independently directed or co-directed. There is a need to challenge teachers' beliefs in the affordances of the technology tool in and of itself for transforming practice. There are specific challenges in relation to the impact of ICT on traditional teaching skills and practices such as, in this study, note-taking and questioning. However, important issues such as teacher technology use for the development of deep conceptual understanding and application - and meeting differentiated student needs - were not mentioned. Teachers' post-lesson observation 'talk-back' reveal teacher ideas showed potential for more transformative practice. The webquest project-based lesson activities showed more evidence of shift in teacher understanding in relation to, for example, the valuing of student co-construction of knowledge and co-solving of problems than other intervention activities. The student voice appears to have a powerful effect on participating teachers.

The recommendation for *SIPSE programme design level* is for intensifying the focus on classroom teaching and learning processes of ICT integration as a basis for professional learning and development. The use of live classroom enactments or video of classroom episodes can provide data to better inform programme design that is based on teacher needs and context challenges. The data can be used more systematically in blended learning platforms and school-based professional development to support deeper teacher reflection and 'talk-back' on current practices and promote teacher capacity for exploring, negotiating and designing ideas to improve and innovate practice.

More specifically, as demonstrated in the SIPSE pilot, the teacher ‘talk-back’ data can serve as a basis to challenge teacher tacit assumptions of ICT use to support traditional modes of knowledge transfer and develop collective understandings of new tentative ways for ICT use that are responsive to the needs and involvement of their learners for sharing and co-construction of knowledge.

At a *research and providers’ level* the recommendation is for a more in-depth exploration of the local settings – the ‘classroots realities’ (O’Sullivan, 2005, p305) in which teachers work and the ‘tacit knowledge’ or teachers’ ‘know how’ (Moreno, 2005, p7) to achieve teaching and learning objectives within the affordances of classroots realities. The research and development agenda should seek to validate rather than dismiss teacher tacit understandings as a basis for professional learning. The need is for research and development of professional learning models that build in teacher co-research and co-design capacity to explore ideas for technology use using the classroom locale and teacher tacit knowledge as key ‘epistemic’ resources (Koh *et al*., 2015b p459).

Recommendations 4: ICT Infrastructure and Resources

The findings revealed a tendency for teachers’ focus (even given tentative signs of change toward the end of the programme) to be on less sophisticated technology uses which support rather than transform existing practice. There was an emphasis on the use of more accessible tools such as presentation software to fast track reproductive learning.

At a *SIPSE programme level* the recommendation would be for more in-depth exploration of technology hardware and software available to teachers and students in schools as a means for promoting more innovative and sophisticated use. This would include the development of more graduated exemplary curriculum materials for sophisticated usage with ICT-STEM design teams. It would also involve the exploration of alternative designs for technology use inside and outside classrooms (computer laboratory, mobile phones) to enable teacher exploration of more creative and flexible technology usage for deeper learning envisaged in the teacher design team discourse.

At *policy level* the recommendation is for policy dialogue from national institutional to school level to clarify the potential and parameters for use of alternative technology integration models – inclusive of the use of mobile telephony in resource challenged environments – given the often contentious issues of mobile telephone use in school environments.

Recommendations 5: Organization of Learning/ Design of Learning Spaces

There is a need for research in the design of learning spaces to take account of the complexities of school and classroom contexts for teacher innovation application. The findings pointed to uncertainty about the role of the teacher and good teaching in relation to the effective integration of ICT in the emerging ecology of 21st century learning classrooms.

At a *research and professional development level* the changing modes of teacher applications of technology pedagogy knowledge (TPK) necessitate research and development into implications for change in the 'grammar' of schooling learning ecosystems and the changing profile of teachers in the 21st century learning classroom. First, the recommendation is to further research how teaching and learning spaces, teacher and learner roles, organization and timetabling of subject teaching should be (re) conceptualized to promote 21st century learning in STEM subjects. Second, the recommendation is to examine how teacher profiles should be (re) conceptualized in the disruption and shifts from their signature practices with technology integration - such as tentative shifts teachers experienced in the SIPSE intervention from knowledge transfer mode to facilitators of knowledge sharing approaches and from isolated professionals to members of teacher design teams.

Recommendations 6: Teacher Professional Learning

The findings presented a clear but partial move from technology literacy to knowledge deepening in the teachers' professional learning journey. Professional development programmes need to take account of the fact that professional development is not necessarily a linear process. There were weaknesses in the SIPSE programme design in relation to building upon the potential of teacher group cognition and teachers' incipient design ideas. There appears to be an important role for expert outsiders. There appeared to be a need to embed more emphatically in the professional development programme a component for collective and continual teacher design conversations and to encompass these in future models of professional development in relation to the effective integration of ICT in practice.

At a *SIPSE programme design level* the recommendation is to focus on building school capacity as a learning organization rooted in teacher knowledge sharing and building for ICT integration that is centred on classroom practices for improving student STEM 21st century learning. This would require a re-design component for strengthening leadership development to define school vision and action plans that embed teacher on-going professional learning not just to integrate technology but to explore design ideas for innovative uses of available technology to support 21st century learning inherent in curriculum reform agendas. At the heart of the professional learning would be continuous dialogue on more complex and sophisticated uses of technology use that can enable teachers to shift from technology literacy to knowledge deepening and knowledge creation levels in their design thinking and applications. This would further require strengthening internal (school-based coordinators) and external (county directorate school support teams, national experts from professional development, curriculum and university institutes) expert to support and enrich teacher design dialogue.

At a *policy level* the recommendation is for reform programmes to integrate adequate support structures at national, county and school directorate levels to negotiate priorities and common goals drawn from national objectives for transformative practice. The focus would be to alleviate tensions that can be created by directives for improved performance and practice to a more developmental approach for building ownership and engagement of teacher education providers, school heads and teacher communities in the transformation agenda. It would include defining models and scenarios from pre-service to in-service to meet the needs of teachers for building competencies in ICT use in curriculum and classroom practice, via face to face, blended learning and open and distance learning platforms (utilizing institution-based, school based, e-learning and m-learning delivery modes).

At a *research and teacher professional development provider level* the recommendation is for design-based models that link the value chain of researcher, practitioner and beneficiaries with the co-design and co-development of feasible solutions that are appropriate to context, that can inform policy and practice and address the issue of transfer to other contexts.

7.4 Contribution to the Knowledge Field

The TPACKtivity framework in Figure 7.1 presents a consolidated overview of the SIPSE intervention of teacher professional development for ICT use in classroom practice that is based on the research findings and recommendations. Many aspects of the framework are articulated in the literature and show graphically a composite view of intervention points that can generate tensions, contradictions and opportunities for new learning. More original contributions contained in the framework lie in its convergence mapping of the ‘what’ (TPACK) and the ‘how’ (AT) of the SIPSE programme (ICT-CFT) implementation. The framework further maps organizational, activity and outcome levels and processes that can promote critical discourse between educator stakeholders and enable knowledge and information flows around emerging technology-enhanced classroom practices that can inform the design and re-design of professional development models.

The organizational aspects encompass first the national ministerial, teacher education, curriculum and teacher services institutions that define the wider context of policies, resources and educational reform. The recommendation at this level was for strengthening ICT policy articulation and engaging in a developmental approach that balances performance, quality and innovation requirements of new educational reform agendas (curriculum and professional development). The developmental approach can be informed by action oriented design-based research and learning that captures knowledge flows of innovative practice emerging from the classroom as centre stage and classroom processes of teaching and learning with and through ICT. The connections between the aims of national vision, policies for ICT integration and 'questions about why they matter' (Loveless, 2011, p311) can be explored and negotiated through fostering 'collective, constructive and conversational learning practices' (Hannay et al., 2013, p66) with educators in school, county and teacher education institutions.

Second, schools and counties can engage in collectively defining school vision and action plans for shaping the object of ICT integration that is in alignment with national vision and policy dialogue. Priorities and common goals drawn from national education and international development objectives for transformative practice and sustainable development[32] can be negotiated in school clusters with county directorates. School strategies and action plans can map a more systematic approach for ICT integration to include domains of leadership and vision promoting a school culture of ICT tool use (TK), ICT integration across the curriculum (TCK), and teacher professional learning communities of practice engaged in collective and continuous dialogue to explore design ideas for innovative technology use for 21st century learning inherent in national curriculum reform agendas (TPK).

Third, teacher education institutions and providers from pre- and in-service can consider development of models for ICT integration that are based on shared vision for action from national to school levels. There is potential to utilize priority competencies from national contextualized ICT Competency Frameworks for Teachers as a basis for harmonizing pre-and in-service teacher education and model development. There is a need to recognize the non-linear and episodic nature of teacher professional learning. Application of mechanistic phased approaches in sequential fashion across multiple school settings for a 'once off' approach should be avoided. Exploration of multiple scenarios (institution-based, school-based, e-learning, m-learning, open and distance learning) can

[32] Sustainable Development Goal 4: Quality education - Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all; Sustainable Development Goal 8: Good Jobs and Economic Growth - Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all (UN, 2015)

be considered for programme development tailored to teacher (students, practising teachers), school and society requirements.

The centre of the framework focuses on classroom activities for STEM 21st century learning. The classroom encompasses the ‘sweet spot’ (Mishra, 2017) of convergence between teacher applications of pedagogy, technology and content knowledge constructs (TK, TCK, TPK and TPACK), throughout cycles of their ICT competency professional learning (technology literacy, knowledge deepening and knowledge creation), within the context affordances of their school and classroom practices (tools, rules, communities, roles, object of ICT in teaching and learning). The classroom is the centre stage for informing practice, policy and research strategies focused on enabling teachers to explore the ‘Why?’, ‘What?’ and ‘How?’ questions for ICT use – as in the critical questions articulated in the teacher ‘talk back’ (Koh *et al.*, 2015a, p88) presented in this research study findings: What were the teachers’ technology pedagogy knowledge (TPK) strategies in each cycle of professional learning and practice with and through ICT? How did they change the roles of the teacher and learner as co-teachers and co-designers of classroom activities? How did other factors at classroom, school or system level influence [or not] the change in roles? Why did pedagogical approaches for more interactive learning and higher order thinking matter?

In this regard, the final level of outcomes will ultimately be dependent on engaging teachers in the articulation of their design ideas for ICT use. The key learning will centre on the evolving nature of how teachers perceive ICT use: whether as a ‘tool’ for enhancing traditional tasks towards STEM conceptual understanding; or as an ‘epistemic resource’ (Koh *et al.*, 2015b, p459) that can change the very essence of the task itself - in alignment with national agendas for building student transferrable knowledge and skills in STEM adequate for transformational and sustainable development. Transforming teacher roles from solitary practitioners in classroom units to team practitioners pro-actively engaged in professional learning and curriculum design and re-deign for ICT integration requires alignment of vision and action at every system level (McDonough & Le Baron, 2010; Butler *et al.,* 2013; Hannay *et al.*, 2014; Asia Society, 2015). The framework illustrates how policy at macro (Ministry of Education, Teacher Education Department, Curriculum, Teacher Service Commission), meso (Teacher Education Institutions, Pre- and In-service) and micro (County Directorates, School Management, Classroom Practice) levels needs to connect vision and action planning for ICT integration.

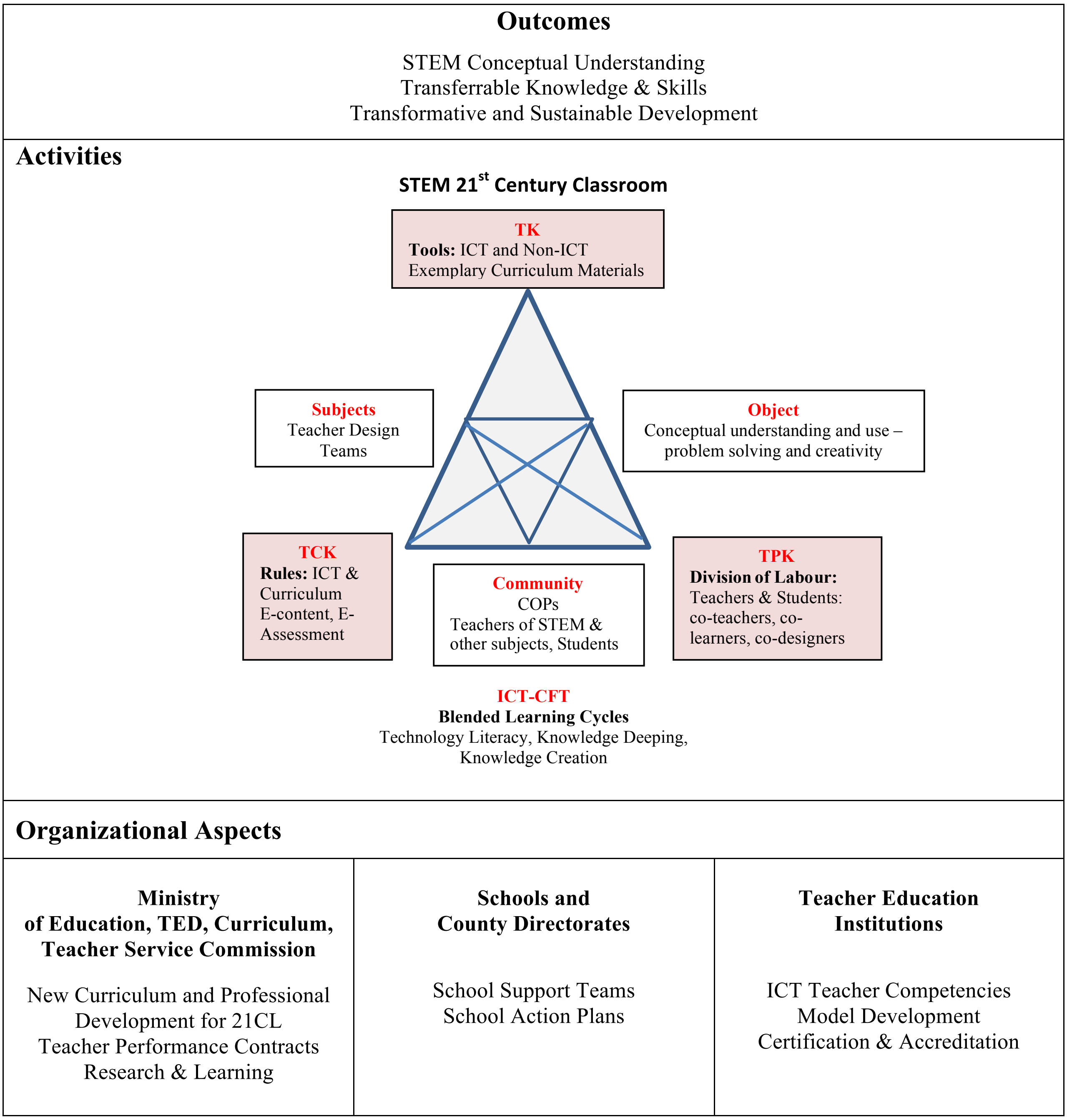


Figure 7.1 - TPACKtivity Framework: System Vision and Action towards TPD for ICT in Classroom Practice

The value of a framework like this lies not so much in the model of professional development it presents, as in the underlying processes it maps for engaging stakeholder conversation at all system levels in negotiating visions and actions for reforming and transforming teacher development for ICT use in classroom practice. The framework may encourage policy maker and provider discourse to appraise and develop models for professional development more comprehensively for informing policy and practice towards achieving 21st century teaching and learning. The framework can support dialogue around research designs that goes beyond programme evaluation of what works to a deeper appraisal of how effectively interventions work in the messy realities of classroom settings to effect authentic change. Finally, the framework can support teacher continuous conversations to explore new technology and pedagogy strategies to enhance and transform teaching and learning and in so doing to articulate, create and share new knowledge on ICT use emerging from the context of their classroom practices.

7.5 Future Research and Final Reflection

There is much work going on in models for teacher development that integrate the UNESCO ICT Competency Framework for Teachers (ICT-CFT) central to the design of the SIPSE programme intervention. In 2015 the researcher participated in a UNESCO East African Community colloquium[33] attended by several regional country representatives in the processes of contextualizing the ICT-CFT for national pilot implementation in pre-service and in-service programmes. The requirement as outlined by Mr. Fengchun Miao (2015) in the colloquium was for more robust research on the impact of these interventions. Butler *et al*. (2013) in a team consultative paper for the 'Irish National Digital Strategy for Schools' note that frameworks like the ICT-CFT may be useful – but there is a need to consider the type of research required to inform policy and evidence-based decision making related to such systematic and systemic innovation. This researcher would agree.

The SIPSE pilot intervention has since been developed into the 'African Digital Schools Initiative' (ADSI) to be implemented in three cycles of digital school and teacher professional development in Kenya, Tanzania and Cote D'Ivoire during 2017-2020. The ADSI programme represents a SIPSE upscale with strengthened components for institutionalization, building leadership capacity for planning and developing whole-school ICT integration towards Digital Schools of Distinction, and for continuous monitoring, evaluation, research and learning. Whether the ADSI upscale should integrate a randomized control testing (RCT) research design for more robust evidence of impact or whether the need is for a continuation of a design-based research approach to understand the deeper questions of context and innovation intervention raised by this study, constitute key questions and areas for future research. The need may be for a combination of such research design frames to maintain a balance between judgements of the efficacy of the intervention (RCT), and the need to contextually understand the myriads of factors at play in school settings that can both hinder and enable innovative practice with and through ICT (DBR).

[33] The colloquium theme was on *Taking the Qingdao Declaration Forward - Seizing digital opportunities in East Africa to lead education transformation*

On a personal reflection note, the opportunity to conduct research in teacher professional development for ICT use in classroom practice has been both exciting and challenging. As a researcher and a teacher this study has provided a unique experience to investigate more deeply the literature, to listen to the voices of teachers and head teachers, and from this to attempt to map and understand the new landscape of teacher professional learning and its critical place in preparing the next and future generations of learners in our twenty first century age of uncertainty and hope. The researcher closes with this quote from Fullan (2007, p219) on teachers and educational change. Whether we speak of change in real or virtual classrooms, teachers and the art of good teaching will always be central to the quality of educational provision, reform and newform.

Educational change depends on what teachers do and think. It is as simple and complex as that.

REFERENCES

Adam, L., Butcher, N., Tusubiri, F.F. and Sibthorpe, C. 2011. *Education Transformation-Ready: The strategic application of communication technologies in Africa* [Online]. Available at: http://www.kubatana.net/docs/inftec/etransafr_executive_summary_111206.pdf [Accessed 9 January 2015]

Adler, P.A. and Adler, P. 2008. Of Rhetoric and Representation: The Four faces of Ethnography, *The Sociological Quarterly,* 49, pp1 – 30

African Union (AU) 2015. *Agenda 2063: Vision and Priorities* [Online]. Available from AU at: http://agenda2063.au.int/en/vision [Accessed 24 July 2016]

African Union (AU) 2016. *Continental Education Strategy for Africa 2016-2025* [Online]. Available from AU at: http://www.au.int/en/documents/29958/continental-education-strategy-africa-2016-2025 [Accessed 24 July 2016]

Agyei, D.D. and Voogt, J. 2011. Determining Teachers' TPACK through observations and self-report data. *IN: Proceedings of Society for Information Technology & Teacher Education International Conference,* 2011. AACE, pp. 2314-2319 Akyeampong, K. 2002. Reconceptualising Teacher Education in the Sub-Saharan African Context, *Journal of International Cooperation*, 5 (1) pp11 - 30

Akyeampong, K. 2016. Relevant Mathematics and Science Education in the Transformative Shift of Africa, Keynote Address at the *Regional Conference of Mathematics and Science Education in Africa,* Nairobi, Kenya, 15 – 17 March, 2016

Alabdulkareem, S. A. 2015. Exploring the Use and the Impacts of Social Media on Teaching and Learning Science in Saudi, *Science Direct, Procedia – Social and Behavioural Sciences,* 182, pp213-224

Albion, P. Jamieson-Proctor, R. and Finger, G. 2009. *Auditing the TPACK Confidence of Australian Pre-Service Teachers: The TPACK Confidence Survey (TCS)* [Online]. Available at: https://eprints.usq.edu.au/8635/1/Albion_Jamieson-Proctor_Finger_Book_Chapter_AV.pdf [Accessed 7 January 2015]

Anderson, T. and Shattack, J. 2012. Design-Based research: A Decade of Progress in Education Research, *Educational Research,* 41 (1) pp16-25

Angeli, C. and Valandies, N. 2009. Epistemological and methodological issues for the conceptualization, development, and assessment of ICT–TPCK: Advances in technological pedagogical content knowledge (TPCK), *Computers and Education*, 52 pp154 - 168

Ang'ondi, E. F. 2013. Teachers Attitudes and Perceptions in the Use of ICT in Teaching and Learning as Observed by ICT Champions, *X World Conference on Computers in Education*, July 2-5, 2013; Toruń, Poland

Aristovnik, A. 2012. The Impact of ICT on Educational Performance and It Efficiency in Selected EU and OECD Countries: A Non-Parametric Analysis, *The Turkish Online Journal of Educational Technology,* 1 (3) pp144-152

Asia New Zealand Foundation 2016. *NZ educators building classroom connections in Singapore* [Online]. Available at: http://www.asianz.org.nz/media-release/nz-educators-building-classroom-connections-singapore [Accessed 14 May 2017]

Asia Society 2015. Encouraging Innovation to Create Twenty First Century Learning Environments, in *Implementing Highly Effective Teacher Policy and Practice: The 2015 International Summit on the Teaching Profession* [Online]. Available at: http://www.cmec.ca/Publications/Lists/Publications/Attachments/344/ISTP%20Asia%20Society%20report_Final_EN.pdf [Accessed 18 April, 2016] (pp24 – 29)

Atkins, L. and Wallace, S. 2012. *Qualitative Research in Education*, London: Sage Publications Ltd.

Austen, A. and Martin, C. 2015. Reflections on using the Raspberry Pi in schools to make learning programming fun, Brooks e-Journal of Learning and Teaching, 7 (1) [Online]. Available from Oxford Brooks University at: http://bejlt.brookes.ac.uk/articles/reflections-on-using-the-raspberry-pi-in-schools-to-make-learning-programming-fun/ [Accessed 15 May 2017]

Bamiro, O. A. 2007. A Framework for the Strategic Design of Science and Technology Policy for African Development, *African Development Review* 19 (1), pp217-255

Berg, B.L. 2009. *Qualitative Research Methods: For the Social Sciences*, Seventh Edition, Boston: Pearson.

Birmingham, D. and Engmann, M. 2012. *Innovation Models for Skills Enhancement in Africa and Asia* [Online]. Available at: http://resultsfordevelopment.org/sites/resultsfordevelopment.org/files/resources/ISESE%20Models%20Synthesis_Final.pdf [Accessed 7 April 2015}

Blanchard, M. R., Harris, J. and Hofer, M. 2011.*Science learning activity types. Mathematics learning activity types, Language learning activity types* [Online]. Available from College of William and Mary, School of Education, Learning Activity Types Wiki at: http://activitytypes.wmwikis.net/file/view/ScienceLearningATs-Feb2011.pdf, [Accessed 25 March 2016]

Boschman, F., Mc Kenny, S. and Pieterst, J. and Voogt, S. 2016. Exploring the role of content knowledge in teacher design conversations, *Journal of Computer Assisted Learning*, Early View, pp1-13

Bourke, B. 2014. Positionality: Reflecting on the Research Process, *The Qualitative Report,* 19 (8) pp 1-9

Braun, V. and Clarke, V. 2006. Using thematic analysis in psychology, *Qualitative Research in Psychology,* 3, pp77-101

Bryman, A. 2012. *Social Research Methods,* 4th Edition. Oxford: University Press

Burnett, N. and Jayaram, S. 2012.. *Skills for Employability in Africa and Asia ISESE Skills Synthesis Paper. Results for Development Institute* [Online], Available at: http://www.resultsfordevelopment.org/sites/resultsfordevelopment.org/files/resources/ISESE%20Skills%20Synthesis_Final_0.pdf [Accessed 7 January 2015]

Butler, D., Leahy, M., Shiel, G. and Cosgrove, J. 2013. *A Consultative Paper: Building Towards a Learning Society: A National Digital Strategy for Schools* [Online]. Available at: http://www.education.ie/en/Schools-Colleges/Information/Information-Communications-Technology-ICT-in-Schools/Digital-Strategy-for-Schools/Building-Towards-a-Learning-Society-A-National-Digital-Strategy-for-Schools-Consultative-Paper.pdf, [Accessed 31 January, 2016]

Cerbin, W. and Kopp, B. 2006. *Lesson Study as a Model for Building Pedagogical Knowledge and Improving Teaching*, International Journal of Teaching and Learning in Higher Education, 18 (3), pp250-257

Centre for Activity Theory and Development Work Research 2003. The Activity System [Online]. Available at: http://www.edu.helsinki.fi/activity/pages/chatanddwr/activitysystem [Accessed 19 April 2012]

Central Intelligence Agency 2016. *World Fact Book: Kenya* [Online]. Available at: https://www.cia.gov/library/publications/the-world-factbook/geos/ke.html [Accessed 26 August, 2016]

Chai, C.S., Koh, J.H.L., Tsai, C.C. and Tan, L.L.W. 2011. Modelling Primary School Pre-service Teachers' Technological Pedagogical Content Knowledge (TPACK) for Meaningful Learning with Information and Communication Technology (ICT), *Computers & Education,* 57, pp1184–1193

Chai, C.S., Koh, J. H. L. and Tsai, C. C. 2013. A Review of Technological, Pedagogical and Content Knowledge, *Educational Technology & Society,* 16 (2), pp31 – 51

Choi, B., Jung, J. and Baek, Y. 2013. In what way can technology enhance student learning? : A preliminary study of Technology Supported learning in Mathematics, in McBride, R. and Searson, M. (Eds.), *Proceedings of Society for Information Technology & Teacher Education International Conference 2013*, pp. 3-9

Coe, R., Aloisi, C. Higgins, S. and Major, L. E. 2014. *What makes great teaching? Review of the underpinning research*, Durham: Durham University

Cohen, L., Manion, L, and Morrison, K. 2007. *Research Methods in Education,* 6th Edition. Abingdon, Oxon: Routledge

College of William and Mary, School of Education 2015. *TPACK Assessments* [Online]. Available at: http://activitytypes.wmwikis.net/Assessments [Accessed 25 May 2015}

Collis, B., and Moonen, J. 2001. *Flexible Learning in a Digital World*. London: Kogan

Commonwealth of Australia, Commonwealth Department of Education Science and Training 2002. *Raising the Standards: A proposal for the Development of an ICT Competency Framework for Teachers* [Online]. Available at: http://pandora.nla.gov.au/pan/32689/20030102-0000/www.dest.gov.au/schools/publications/2002/RaisingtheStandards/RaisingtheStandards.pdf [Accessed 3 April 2015]

Commonwealth of Learning 2012a. *Information and Communication Technologies: Professional Development Strategy for Teachers in Guyana: A Case Study* [Online]. Available at: http://www.col.org/PublicationDocuments/Guyana-casestudy_web_96.pdf [Accessed 29 August 2013}

Commonwealth of Learning 2012b. *Commonwealth Certificate for Teacher's ICT Integration* [Online]. Available at: http://schoolnet.org.za/CoL/ACE/ [Accessed 10 January 2015]

Coolahan, J. 2002. *Teacher Education and the Teaching Career in the Era of Lifelong Learning*. OECD Education Working Paper No. 2. Paris: OECD

Coolahan, J. 2010. The Development of Q.A. within Teacher Education Policy in Ireland. *IN: Colloquium on Quality Assurance in Teacher Education,* UCD, 21 June, 2010

Copley, A. 2014. *Africa in the News – Kenya become a Middle-Income Country* [Online]. Available at: http://www.brookings.edu/blogs/africa-in-focus/posts/2014/10/03-kenya-middle-income-mo-ibrahim-index-south-sudan-copley [Accessed 15 December 2014]

Cowan, P. 2011. *ESCalate Themed Funding: Teacher Educators for the 21st Century – Grant Project Final Report*, Belfast, Queen's University Belfast

Cowan, P. 2015. How do school mentors view their role when supporting pre-service or novice teachers? *IN: European Conference on Educational Research*, Budapest, 7 – 11 September, 2015 [Online]. Available at: http://www.eera-ecer.de/ecer-programmes/conference/20/contribution/34624/ [Accessed 29 August 2016]

Cuban, L. 2002. *Oversold and Underused: Computers in the Classroom*, Cambridge, Massachusetts; London, England: Harvard University Press

Dahlman, C. 2007. Issues Paper: Innovation in the African Context in *A Forum for Policymakers*, sponsored by Development Cooperation Ireland and the World Bank Institute, March 6-8, Dublin, Ireland

Daily Nation 2014. *Kenya Facing a Shortage of Over 100,000 Teachers* [Online]. Available at: http://mobile.nation.co.ke/counties/Kenya-teacher-100000-shortage/-/1950480/2410160/-/format/xhtml/-/alf9qxz/-/index.html [Accessed 29 June 2015]

Daily Nation Friday, 25 March, 2016. *Kenya National Council's Examination Board Dissolved Over Exam Leakage* [Online]. Available at: http://www.nation.co.ke/news/KNEC-board-dissolved-over-exam-cheating/-/1056/3131860/-/9icl8o/-/index.html, [Accessed 25 March, 2016]

De Almeida, F. J. and Franco, M. G. 2013. Technologies for Education and Curriculum Public Policies, *in* Brazilian Internet Steering Committee (2013) *ICT Education 2013: Survey on the Use of Information and Communication Technologies in Brazilian Schools* [Online]. Available at: http://www.cetic.br/media/docs/publicacoes/2/tic-educacao-2013.pdf [Accessed 12 February 2017]

De Angelis, S. F. September 4, 2015. *STEM Education Helps Teach Skills Necessary for 21st Century Success* [Online]. Available from Enterra Insights Blog at: http://www.enterrasolutions.com/2015/09/stem-education-helps-teach-skills-necessary-for-21st-century-success.html [Accessed 25 July, 2016]

Dede, C. 2014. *The Role of Digital Technologies in Deeper Learning* [Online]. Available from Harvard University at: http://www.jff.org/sites/default/files/publications/materials/The-Role-of-Digital-Technologies-in-Deeper-Learning-120114.pdf [Accessed 14 May 2017]

Dewey, J. 1910. *How we think*, Lexington, Massachusetts: D. C. Heath.

Demirsalem, Y. and Usluel, Y.K. 2008. ICT integration processes in Turkish schools: Using activity theory to study issues and contradictions *Australasian Journal of Educational Technology,* 24 (4), pp458-474.

Drenoyianni, H. 2006. Reconsidering change and ICT: Perspectives of a human and democratic education, *Education and Information Technologies,* 11(3), pp401-413

Drucker, P. 1993. *Post-capitalist Society*, New York, Harper Collins

Dodge, B. 2015. *What is a Webquest?* [Online]. Available at: http://webquest.org, accessed 22 November, 2015

Dodge, B. and Pickett, N. 2007. *Creating rubrics for web lessons* [Online]. Available at: http://webquest.org/sdsu/rubrics/weblessons.htm [Accessed 8 July 2016]

Education for All (EFA) Global Monitoring Report Team 2015. *Investing in teachers is investing in learning: A pre-requisite for the transformative power of education: Background paper for the Oslo summit on education for development* [Online]. Available at: http://en.unesco.org/gem-report/investing-teachers-investing-learning-prerequisite-transformative-power-education#sthash.zJEqSKCQ.dpbs [Accessed 6 August 2016]

EDUCAUSE 2012. *7 Things You Need to Know About a Flipped Classroom* [Online]. Available at: https://net.educause.edu/ir/library/pdf/eli7081.pdf, [Accessed 16 April, 2016]

Egyptian Education Initiative 2008. *Learning and Technology Policy Framework: Professional Development about EEI* [Online]. Available at: http://www.eei.gov.eg/pages/08%20News/News_sub.aspx?id=32 [Accessed 10 January 2015]

Eison, J. 2010. *Using Active Learning Instructional Strategies to Create Excitement and Enhance Learning* [Online]. Available at: http://www.cte.cornell.edu/documents/presentations/Eisen-Handout.pdf [accessed 21 June 2016]

Engeström, Y. 2001. Expansive Learning at Work: toward and activity theoretical reconceptualization, *Journal of Education and Work* 14 (1), pp 133-156.

Engeström, R. 2003. *Change lab – a new perspective to teachers' professional development* [Online]. Available from WITFOR at: www.witfor.org.bw/doc/dr_ritva_education.ppt, [Accessed 29 March 2015]

Engeström, R. Hakkarainen, T., Newhan, D.S., Nleya, P. Senteni, A. and Sinko, M. 2014. *Reflections on Change Laboratory: Toward a dynamic interplay of global and local forces in designing change in education* [Online], available at: https://helsinki.academia.edu/KaiHakkarainen [Accessed 29 March 2015]

e-Learning Industry, 2016. *15 ways to use Twitter in Education (for students and educators alike)* [Online]. Available at: https://elearningindustry.com/15-ways-twitter-in-education-students-teachers [Accessed 14 May 2017]

Elo. S., Kääriäinen, M., Kanste, O., Pölkki, T., Utriainen, K. and Kyngäs, H. 2014. Qualitative Content Analysis: A Focus on Trustworthiness, *SAGE Open*, January-March 2014, pp1-10

European Union (EU) Go-Lab Project 2017. *Global Online Science Labs: Inquiry Learning at School* [Online]. Available at: http://golab.ea.gr/sites/default/files/Go-LabLeafletEnglish.pdf [Accessed 14 May 2017]

Evoh, C. J. 2007. Collaborative stakeholderships and the transformation of secondary education through ICTs in South Africa, *Educational Media International*, 44(2), pp 81-98

Farrell, G. and Isaacs, S. 2007. *Survey of ICT in Education in Africa Volume 2: 53 Country Reports* [Online]. Available from *info*DEV at: http://www.infodev.org/en/Publication.354.html [Accessed 04 June 2010]

Figg, C. and Jaipal, K. 2012. TPACK-in-Practice: Developing 21st Century Teacher Knowledge. In P. Resta (Ed.), *Proceedings of Society for Information Technology & Teacher Education International Conference 2012* (pp. 4683-4689).

Finger, G., Jamieson-Proctor, R., and Albion, P. 2010. Beyond Pedagogical Content Knowledge: The Importance of TPACK for Informing Preservice Teacher Education in Australian *Key Competencies in the Knowledge Society,* IFIP Advances in Information and Communication Technology Volume 324, 2010, pp 114-125

Fisher, L., Oldham, E., Milwood, R., Fitzgibbon, A. and Cowan, P, 2016. Recognising and Addressing Inertia Affecting Teacher Education: A case Study Considering Computer Science in the Republic of Ireland, *Journal of the World Federation of Associations of Teacher Education*, 1 (3a) pp81-102

Foot, K. 2001. Cultural-Historical Activity Theory as Practical Theory: Illuminating the Development of a Conflict Monitoring Networks, *Communication Theory,* 11 (1), Pp56-83

Fullan, M. 2007. *The New Meaning of Educational Change.* Fourth Edition. New York: Teachers College Press

Gacicio, E.W. 2013. Moving Teachers' Competencies in Curriculum Delivery to 21st Century Learning: Kenyan Perspectives, in *E-Learning Africa: Book of Abstract*, Moafari Conference Centre Windhoek, Namibia, May 29-31, 2013

Gakuu, C.M. and Kidmobo, H.J. 2008. Closing the Chasm: Are secondary school teachers in Kenya using ICTs effectively to deliver curriculum content?, in *Report on PanaAf participation in the 3rd International conference on ICT for Development, Education and Training: An Annual Event for Developing E-learning Capacities in Africa*, Accra - 2008. [Online] http://www.ernwaca.org/panaf/IMG/pdf/Report_of_the_3rd_International_conference_on_ICT_for_Development.pdf [Accessed 28 June 2015]

Gakuu, C. M., Kidombo, H. J., Bowa, O., Ndiritu, A., Mwangi, A. and Gikonyo, N. (2009) *The Pan African Research Agenda on the Pedagogical Integration of ICTs: Kenya Report* [Online]. Available at: http://www.ernwaca.org/panaf/pdf/phase-1/Kenya-PanAf_Report.pdf, [Accessed 20 March 2016]

Gardiner, B. 2014 Adding Coding to the Curriculum, *The New York Times, March 23, International Education* [Online]. Available at: https://www.nytimes.com/2014/03/24/world/europe/adding-coding-to-the-curriculum.html?_r=0 [Accessed 14 May 2017]

Global E-Schools and Communities Initiative (GESCI) 2016. *GESCI Medium-Term Strategy (2017-2020): From Vision to Action – Delivering What We Promise*, Nairobi, GESCI

Government of Kenya, Ministry of Education 2006. *National Information and Communication Technology (ICT) Strategy for Education & Training* [Online]. Available at: http://www.nepadkenya.org/documents/MOE-ICT%20in%20Education.pdf [Accessed 8 January 2015]

Government of Kenya, Ministry of State for Planning, National Development and Vision 2030 2008. *Vision 2030: A Globally Competitive and Prosperous Kenya - First Medium Term Plan 2008 – 2012* [Online]. Available at: http://www.healthresearchweb.org/files/A%20globally%20competitive%20and%20prosperous%20Kenya%20(2008-2012).pdf [Accessed 8 January 2015]

Government of Kenya, Ministry of Education 2012 *The National ICT in Education Strategy: Chapter Seven (in revision),* Nairobi, MoE

Government of Kenya 2013. *The Basic Education Act 2013* [Online], available at: http://planipolis.iiep.unesco.org/upload/Kenya/KenyaBasicEducationActNo_14of2013.pdf [Accessed 12 July 2015]

Government of Kenya 2015. *Kenya Open Data* [Online]. Available at: https://opendata.go.ke/ [Accessed 3 March 2015]

Gray, C. and MacBlain, S. 2012. *Learning Theories in Childhood*, London: SAGE Publications

Groth, R., Sprickler, D., Bergman, J. and Bardzell, M. 2009. A qualitative approach to assessing technological, pedagogical and content knowledge, *Contemporary Issues in Technology and Teacher Education,* 9 (4) pp392-441

Guile, D. 2010. *The Knowledge Economy and Education: The Learning Challenge of the Knowledge Economy*, Rotterdam; Boston; Taipei: Sense Publication

Haßler, B., Major, L., Warwick, P., Watson, S., Hennessy, S. and Nicholl, B. 2016. *Perspectives on Technology, Resources and Learning: Productive Classroom Practices, Effective Teacher Professional Development* [Online]. Available from Faculty of Education, University of Cambridge at: https://www.educ.cam.ac.uk/people/staff/watson/Hassler%20et%20al%202016%20-%20Perspectives%20on%20Technology,%20Resources%20and%20Learning%20(Full).pdf [Accessed 14 May 2017]

Haddad, G. 2007. Welcome Address, in *Teacher Policy Forum for Sub-Saharan Africa* November 2007, UNESCO Paris [Online]. Available from UNESCO at: http://unesdoc.unesco.org/images/0016/001627/162798e.pdf [Accessed 8 April 2009]

Halkier, B. 2010. Focus group as social enactments integrating interaction and content in the analysis of focus group data, *Qualitative Research,* 10 (1) pp 71-86

Hannay, L., Jaafar, S. B. and Earl, L. 2013. A case study of district leadership using knowledge management for educational change, *Journal of Organizational Change Management*, 26 (1) pp64-82

Hammerseley, M. 2004. Countering the 'new orthodoxy' in educational research: a response to Phil Hodkinson, *British Educational Research Journal*, 31 (2) pp139 - 155

Hammond, M. 2010. *What is an affordance and can it help us understand the use of ICT in education?* [Online]. Available from Warwick University at: http://wrap.warwick.ac.uk/34602/ [Accessed 28 June 2015]

Hammond, M. 2013. Researching Teacher Take-Up of ICT: Past Perspectives and Present Day Challenges, in *World Conference on Computers in Education, July 2-5, 2013, Toruń, Poland* [Online]. Available at: http://edu.rsei.umk.pl/wcce2013/publications/v1/V1.23_063-Hammond-fullR-FPR.pdf [Accessed 28 June 2015]

Hargreaves, A. 2003. *Teaching in the Knowledge Society*, New York and London, Teachers College Press [Online]. Available at: http://phamtrung.wikispaces.com/file/view/TeachingInTheKnowledgeSociety.pdf/207255650/TeachingInTheKnowledgeSociety.pdf [Accessed 27 April 2014]

Hardman, J. 2005. Activity Theory as a framework for understanding teachers' perceptions of computer usage at a primary school level in South Africa, *South African Journal of Education,* 25 (4), pp258 – 265

Harris, J. B. 2008. TPCK in in-service education: Assisting experienced teachers' 'planned improvisations', in AACTE Committee on Innovation and Technology (eds) (2008) *Handbook of Technological Pedagogical Content Knowledge (TPCK) for Educators*, New York, Routeledge

Harris, J. and Hofer, M. 2010. *Activity types* [Online]. Available from College of William and Mary, School of Education at: http://activitytypes.wmwikis.net/K-6+Literacy [Accessed 7 February, 2016]

Harris, J. Grandgenett, N. and Hofer, M. 2010. Testing a TPACK-based technology integration assessment instrument, in Maddux, C. D., Gibson, D. and Dodge, B. (Eds.) *Research Highlights in technology and teacher education 2010* (pp 323-331), Chesapeake, VA, Society for Information Technology and teacher Education (SITE)

Harris, J., Mishra, P. and Koehler, M. 2011. Teachers' Technological Pedagogical Content Knowledge and Learning Activity Types: Curriculum-based Technology Integration Reframed, *Journal of Research on Technology in Education,* 41(4), pp 393–416

Hinostroza, J.E., Labbe, C., Brun, M. and Matamala, C. 2011. Teaching and learning activities in Chilean classrooms: Is ICT making a difference? *Computers and Education*; 57 (1), pp 1358-1367.

Hofer, M., Grandgenett, N., Harris, J. and Swan, K. 2011. Testing a TPACK-Based Technology Integration Observation Instrument. In M. Koehler & P. Mishra (Eds.), *Proceedings of Society for Information Technology & Teacher Education International Conference 2011* (pp. 4352-4359). Chesapeake, VA: Association for the Advancement of Computing in Education (AACE).

Hofer, M. and Harris, J. 2012. TPACK Research with Inservice Teachers: Where's the TCK?. In P. Resta (Ed.), *Proceedings of Society for Information Technology & Teacher Education International Conference 2012* (pp. 4704-4709), Chesapeake, VA, Association for the Advancement of Computing in Education (AACE).

Hooker, M. 2009. How can I encourage multi-stakeholder narrative and reflection on the use of ICT in Teacher Development Programmes in Rwanda, *Educational Journal of Living Theories,* 2(3), pp234 – 264

InfoDev 2015. *Impact of ICTs on Learning and Achievement* [Online]. Available at: http://www.infodev.org/articles/impact-icts-learning-achievement [Accessed 6 August, 2016]

Isaacs, S. 2006. *Towards a GeSCI Initiative on Teacher Professional Development in Africa*. Dublin: GeSCI

Isroff, K. and Scanlon, E. 2001. *Case studies revisited: what can Activity Theory offer?* Proceedings of International Conference on Computer Supported Collaborative Learning 2001 (CSCL 2001), Maastricht, 22-24 March 2001.

Jaipal, K. and Figg, C. 2010. Unpacking the "Total PACKage": Emergent TPACK Characteristics from a Study of Pre-service teachers Teaching with Technology, *Journal of technology and Teacher Education,* 18 (3), pp415-441

Jaipal-Jamani, K and Figg, C. 2015. The Framework of TPACK-in-Practice: Designing Content-Centric Technology Professional Learning Contexts to Develop Teacher Knowledge of

Technology-enhanced Teaching (TPACK), in Angeli, C. and Valanides, N. (eds), *Technological, Pedagogical, Content Knowledge: Exploring, Developing and Assessing TPCK,* pp 137 - 163

Jamieson-Proctor, R., Finger, G. and Albion, P. 2010. Auditing the TPACK Capabilities of Final Year Teacher Education Students: Are they ready for the 21st Century?, in *ACE 2010: Digital Diversity Conference, 6-9 April 2010, Melbourne, Australia* [Online]. Available at: http://acec2010.acce.edu.au/proposal/248/auditing-tpck-capabilities-final-year-teacher-education-students-are-they-ready-21st [Accessed 11 January 2015]

Jimoyiannis 2010. Designing and implementing an integrated technological pedagogical science knowledge framework for science teachers' professional development, *Computers and Education*, 55 pp1259-1269

Kafyulilo, A., Fisser, P.H.G. and Voogt, J.M. 2013. Supporting teachers' collaboration in design teams to develop Technological Pedagogical Content Knowledge: the case of science teachers in Tanzania, in *Society for Information Technology & Teacher Education International Conference (SITE) 2013*, March 25, New Orleans, 25-03-2013, New Orleans (pp. 4692 - 4697).

Kampylis, P.G., Bocconi, S. and Punie, Y. 2012. *Towards a Mapping Framework of ICT-enabled Innovation and Learning*, Seville, European Commission [Online]. Available at: http://ipts.jrc.ec.europa.eu/publications/pub.cfm?id=5159 [Accessed 4 April 2015]

Kenya Institute of Education 2008. *Life Skills Education* [Online]. Available at: http://wikieducator.org/Life_Skills_Education_(Kenya_Institute_of_Education) [Accessed 12 July, 2015]

Kenya Institute of Curriculum Development, Juang, J. 2016. *Highlights of Key Findings from the Needs Assessment Research for Curriculum Reform in Kenya* [Online]. Available at: http://www.slideshare.net/jmjmwanzo/kicd-curriculum-reform-needs-assessment-findings-report-by-dr-julias-juang-kicd-ceo-april-2016 [Accessed 28 July, 2016]

Kereluik, K., Mishra, P., Fahnoe, C. and Terry, P. 2013. What Knowledge Is of Most Worth: Teacher Knowledge for 21st Century Learning, *Journal of Digital Learning in Teacher Education,* 29 (4) pp127-140

Kirschner, P. and Davis, N. 2003. Pedagogic benchmarks for information and communications technology in teacher education, *Technology, Pedagogy and Education*, 12 (1) pp125 – 147.

Kirschner, P., Wubbels, T. and Brekelmans, M. 2008. Benchmarks for Teacher Education Programs in the Pedagogical Use of ICT, in Voogt, J. and Knezek, G. (Eds.) *International Handbook of Information Technology in Primary and Secondary Education*, New York, Springer

Koehler, M.J. and Mishra, P. 2005. What happens when teachers design educational technology? The development of technological, pedagogical and content knowledge, *Journal of Educational Computing Research,* 32 (2) pp131-152

Koehler, M.J. and Mishra, P. 2008. What is technological pedagogical content knowledge (TPCK)?: Introducing TPCK, in Colbert, J. A., Boyd, K.E., Clark, K.A., Guan, S., Harris, J.B., Kelly, M.A. & Thompson, A.D. (eds) *Handbook of Technological Pedagogical Content Knowledge (TPCK) for Educators*, New York and London, Routledge

Koh, K. 2013. Adolescents' information-creating behavior embedded in digital Media practice using scratch, *Journal of the Association for Information, Science and Technology,* 64 (9) pp 1826–1841

Koh, J.H.L., Chai, C.S. and Tay, L. Y. 2014. TPACK-in-Action. Unpacking the contextual influences of teachers' construction of technological pedagogical content knowledge (TPACK), *Computers & Education,* 28, pp20 – 29

Koh, J.H.L., Chai, C.S. and Lee, M. A. 2015. Technological, Pedagogical, Content Knowledge (TPACK) for Pedagogical Improvement (TPACK), Editorial for Special Issue of TPACK, *Asia-Pacific Education Researcher*, 24 (3) p459

Koh, J.H.L., Chai, C. S., Benjamin, W. and Hong, H. Y. 2015a. Design Thinking and In-service Teachers, in Koh, J.H.L., Chai, C. S., Wong, B. and Hong, H. Y. (2015) *Design Thinking for Education,* Singapore, Springer-Vertag, Singapore

Koh, J.H.L., Chai, C. S., Benjamin, W. and Hong, H. Y. 2015b. Technological Pedagogical and Content Knowledge (TPACK) and Design Thinking: A Framework to Support ICT Lesson Design for 21st Century Learning, *The Asia Pacific Education Researcher,* Regular Article, pp1-9

Lagaarde, C. 2014. *A New Multilateralism for the 21st Century: The Richard Dimbleby Lecture* [Online], available at: https://www.imf.org/external/np/speeches/2014/020314.htm [Accessed 6 January 2014]

Leach, J., Ahmed, A., Makalima, S. and Power, T. 2006. DEEP IMPACT: an investigation of the use of information and communication technologies for teacher education in the global south, in *Researching the issues*, London, Department for International Development (DFID) [Online], available at:
http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.383.3138&rep=rep1&type=pdf
[Accessed 26 February, 2017]

Leach, J. 2008. Do new information and communications technologies have a role to play in the achievement of education for all? *British Educational Research Journal*, 34 (6), pp.783 – 805.

Lee, C.J. and Kim, C.M. 2014. An Implementation Study of a TPACK-based Instructional Design Model in a Technology Integration Course, *Education Technology Research Development,* 62, pp437-460

Lee, M.H. and Tsai, C-C, 2011. Exploring teachers' perceived self-efficacy and technological, pedagogical and content knowledge with respect to educational use of the WorldWide Web, *Instructional Science,* 38 (1), pp1-21

Leinonen, T. Toikkanen, T. and Silfvast, K. 2008. Software as Hypothesis: Research Based Design Methodology, in *ACM Digital Library: Proceedings of the tenth Anniversary Conference on Participatory Design 2008*

Lewis, C., Perry, R. and Murata, A. 2014. How Should Research Contribute to Instructional Improvement? The Case of Lesson Study, *Educational Researcher,* 35 (3) pp3-14

Leye, V. 2007. *UNESCO's Road Toward Knowledge Societies* [Online]. Available at: http://javnost-thepublic.org/article/pdf/2007/4/5/ [Accessed 26 April 2014]

Lim, C.P. and Hang, D.2003. An activity theory approach to research of ICT integration in Singapore schools. *Computers and Education*, 41, pp49-63.

Livingstone, D. W., Smaller, H. and Clarke, R. 2012. *The Knowledge Economy and Education: Teacher Learning and Power in the Knowledge Society*, Rotterdam, Boston, Taipei: Sense Publishers

Lincoln, Y.S. and Guba, E.G. 2005. Paradigmatic Controversies, Contradictions and Emerging Confluences in Paradigms and Perspectives, in Denzin, N.K. & Lincoln , Y.S. (2005) The Sage Handbook of Qualitative Research, London, Sage.

Livingstone, D.W., Smaller, H. and Clarke, R. 2012. *The Knowledge Economy and Education: Teacher Learning and Power in the Knowledge Society,* Potterdany, Boston, Tapei: Sense Publishers

Loveless, A. 2011. Technology, pedagogy and education: reflections on the accomplishment of what teachers know, do and believe in a digital age, *Technology, Pedagogy and Education,* 20 (3) pp 301-316

Maat, H. 2014. *Working Paper: The Active Teaching and Learning Method: Implemented through implemented through Basic Education Quality Improvement Projects (BEQUIP) in various countries* [Online]. Available from Edukans and the University of Amsterdam at: http://www.edukans.org/images/International/The-Active-Teaching-Learning-Method-2014.pdf [Accessed 16 August 2016]

Mandinach, E.B. 2005. The Development of Effective Evaluation Methods for E-Learning: A Concept Paper and Action Plan. *Teachers College Record* [Online]. 107 (8), pp1814-1835. Available at: http://www.library.dcu.ie/Eresources/databases-az.htm [Accessed 15 December 2008]

Master Card Foundation 2013. *Youth Learning: Global E-Schools and Communities Initiative – Why We Partnered.* Accessed from: http://www.mastercardfdn.org/Projects/global-e-schools-and-communities-initiative-gesci,

McDonough, E. and Le Baron, J. 2010. *Research Report for GeSCI Meta-Review of ICT in Education – Phases One and Two* [Online]. Available from GeSCI at: http://www.gesci.org/publications.html, and http://www.gesci.org/assets/files/Research/meta-research-phase2-A.pdf [Accessed 29 August 2013]

Mc Niff, J., Lomax, P. and Whitehead, J. 2007. *You and Your Action Research Project: 2nd Edition*, Oxon, Routledge Farmer

Metcalf, S., Chen, J., Kamarainen, A., Frumin, K., Vickrey, T., Grotzer, T. and Dede, C. (2014) Shifts in Student Motivation during Usage of a Multi-User Virtual Environment for Ecosystem Science, *International Journal of Virtual and Personal Learning Environments,* 5(4), pp 1-15

Miao, F. 2010. *UNESCO ICT Competency Framework for Teachers (ICT-CFT) and Institutional Strategy for Teacher Training on ICT-pedagogy Integration* [Online]. Available at: http://www.unesco.org/new/fileadmin/MULTIMEDIA/HQ/CI/CI/pdf/wsis/UNESCO%20ICT-CFT_FC%20Miao_UNESCO_15May2011.pdf [Accessed 30 June, 2015]

Miao, F. 2015. *Qingdao Declaration and UNESCO's ICT in Education Programme* [Online]. Available at: http://www.unesco.org/new/en/nairobi/about-this-office/single-view/news/taking_the_qingdao_declaration_forward_seizing_digital_opportunities_in_east_africa_to_lead_education_transformation-2/#.V7iwYmDr3IV [Accessed 20 August, 2016]

Mishra, P. and Koehler, M. J. 2006. Technological pedagogical content knowledge: A framework for integrating technology in teacher knowledge, *Teachers College Record*, 108 (6), pp1017-1054.

Mishra, P. 2017. *Punya Mishra's Web: Living at the junction of education, creativity, design & technology: TPACK fun* [Online]. Available at: http://www.punyamishra.com/research/tpack/tpackfun/ [Accessed 15 May 2017]

Moreno, J. M. 2005. *Learning to teach in the Knowledge Society: Final Report*. Washington, World Bank [Online], available at: http://siteresources.worldbank.org/EDUCATION/Resources/278200-1126210664195/1636971-1126210694253/Learning_Teach_Knowledge_Society.pdf [Accessed 27 April 2014]

Mueller, J., Wood, E., Willoughby, T., Ross, C. and Specht, J. 2008. Identifying discriminating variables between teachers who fully integrate computers and teachers with limited integration, *Computers & Education, 51*(4), pp 1523-1537.

Murithu, N., Gitonga, D. and Kimanthi, P. 2013. School ICT Policy, a Factor Influencing Implementation of Computer Studies Curriculum in Secondary Schools, *Journal of Education and Practice,* 4(28) pp197-203

Murphy, C. and Beggs, J. 2006. Co-Teaching as an Approach to Enhance Science Learning and Teaching in Primary Schools, *The Science Education Review*, 5 (2), pp1-10

Mwanza, D. and Engeström, Y. 2003. Pedagogical adeptness in the design of eLearning environments: Experiences from Lab@Future project, in Robertson, I. 2008. Sustainable e-learning, activity theory and professional development. *IN:* Proceedings ascilite Melbourne 2008, November 30 – December 3 [Online], Available from: http://www.ascilite.org.au/conferences/melbourne08/procs/index.htm [Accessed 06 January 2009]

Niles, M. L. 2008.Guiding preservice teachers in developing TPCK *IN:* AACTE Committee on Innovation and Technology (Eds.) *Handbook of Technological Pedagogical Content Knowledge (TPCK) for Educators,* New York, Routledge (pp 223 – 250)

Noble, H. and Smith, J. 2015. Issues of validity and reliability in qualitative research, *Evidence Based Nursing,* 18, pp 34 - 35

Ng, W. Miao, F. and Lee, M. 2008. *Capacity Building for ICT in Integration* [Online]. Available at: http://web.idrc.ca/en/ev-140839-201-1-DO_TOPIC.html [Accessed 8 January 2015]

Nicolopoulo, A. and Cole, M. 2010. Design experimentation as a theoretical and empirical tool for developmental pedagogical research, *Pedagogies: An International Journal,* 5 (1) pp 61-77

Njoroge, S., Kiyiapi, C., Ng'eny, E. and Kizito, M. E. 2016. *Lesson Study as a Model for School Based Teacher Capacity Development in Kenya: A Case Study of Langata West Primary School*, Centre for Mathematics, Science and Technology Education in Africa (CEMESTA), Nairobi

OECD 2014. *Programme for International Student Assessment (PISA): What 15 year-olds know and what they can do with what they know* [Online]. Available at: https://www.oecd.org/pisa/keyfindings/pisa-2012-results-overview.pdf [Accessed 6 August, 2016]

OECD 2015a. *Students, Computers and Learning: Making the Connection* [Online]. Available at: http://www.oecd-ilibrary.org/education/students-computers-and-learning_9789264239555-en [Accessed 6 August, 2016]

OECD 2015b. *New approach needed to deliver on technology's potential in schools* [Online], available at: http://www.oecd.org/education/new-approach-needed-to-deliver-on-technologys-potential-in-schools.htm [Accessed 6 August, 2016]

Olakulehin, F. K. 2007. Information and communication technologies in teacher training and professional development in Nigeria, *Turkish Online Journal of Distance Education* [Online] 8 (1), available from: http://tojde.anadolu.edu.tr/tojde25/pdf/article_11.pdf [Accessed 11 January 2015]

O'Sullivan, M. 2005. What is Happening in the Classroom? A Common–sense Approach to Improving the Quality of Primary Education in Developing Countries, *Teacher Development: An International Journal of Teachers' Professional Development,* 9 (3), pp 301 - 314

Ostler, E. 2012. 21st Century STEM Education: A Tactical Model for Long-Range Success, *International Journal of Applied Science and Technology,* 2 (1) pp28-33

Ottevanger, W., Akker, J. V. D. and Feiter, L. D. 2007. *Developing Science, Mathematics, and ICT Education in Sub-Saharan Africa: Patterns and Premising Practices* [Online]. Available at: http://siteresources.worldbank.org/INTAFRREGTOPSEIA/Resources/No.7SMICT.pdf [Accessed 28 June 2015]

Ouyang, F. 2015. Exploring and Experiencing Online Instructor's Applications of TPACK in a Graduate-Level Online Course through the Online Students' Perspectives: Design of a Qualitative Case Study, in *Educational Media 2015,* Montreal, Quebec, Canada, June 22-24, 2015

Ozgum-Koca, S. A., Meagher, M. and Edwards, M.T. 2011. A Teacher's Journey with a New Generation Handheld: Decisions, Struggles and Accomplishments, *School Science Mathematics,* 11 (5) pp209 - 224

Paavola, S., Lipponen, L. and Hakkarainen, K. 2004. Models of Innovation and three Metaphors of Learning, *Review of Educational Research,* Winter 2004, Vol. 74, No. 4, pp. 557-576

Padilha, M. 2013. From Digital Technologies to Education: A new Culture and New Logics for Teacher Training, in Brazilian Internet Steering Committee (2013) *ICT Education 2013, Survey on the Use of Information and Communication Technologies in Brazilian Schools*, pp 231-236, Sao Paulo, Brazilian Network Information Centre

Passey, D. 2010. Mobile Learning in School Contexts: Can Teachers Alone Make It Happen? *IEEE Transaction on Learning Technologies*, 3, (1), pp68-81

Passey, D. 2014. *Promethean Thinking Deeper Research Paper No. 8: Planning a Teacher Professional Development Journey* [Online]. Available from Lancaster University at: http://www.research.lancs.ac.uk/portal/en/publications/planning-a-teacher-professional-development-journey(1c364ecf-8184-4164-924f-d8d6fac50855)/export.html [Accessed 17 March 2015]

Pelgrum, W. J. and Law, N. 2003. *ICT in Education around the World: Trends, Problems and Prospects* [Online]. Available from UNESCO-International Institute for Educational Planning at: http://publications.iiep.unesco.org/ICT-education-world-trends-problems-prospects [Accessed 7 January 2015]

Power, T., Gater, R., Grant, C. and Winters, N. 2014. *Education Technology Topic Guide* [Online]. Available from DFID Health and Education Advice and Resource Team at: http://www.heart-resources.org/topic/educational-technology/ [Accessed 19 February, 2017]

Pring, R. 2000. The 'False Dualism of Educational Research, *Journal of Philosophy of Education,* 34 (2) pp 247-260

Queen's University Belfast 2014. *Policy and Principles on the Ethical Approval of Research* [Online]. Available at: https://www.qub.ac.uk/home/media/Media,600018,en.pdf [Accessed 29 August 2016]

Reason, P. and Bradbury, H. (eds) 2008 *Handbook of Action Research*, London: Sage Publications

Redecker, C. and Johannessen, Ø. 2013. Changing Assessment — Towards a New Assessment Paradigm Using ICT, *European Journal of Education,* Special Issue: ICT and Education: taking stock of progress and looking at the future, 48, (1), pp 79–96

Robertson, I. 2008. Sustainable e-learning, activity theory and professional development, in *Proceedings Ascilite Melbourne 2008, November 30 – December 3* [Online]. Available from: http://www.ascilite.org.au/conferences/melbourne08/procs/index.htm [Accessed 30 August 2013]

Roth, W.M. and Radford, L. 2010. Re/thinking the Zone of Proximal Development (Symmetrically), *Mind, Culture and Activity*, 17 (4), pp299-307

Sachs, J. 2005. Professional Standards: quality teachers for the future, *Keynote Address presented at Sharing Experience: ways forward on standards conference,* hosted by NIQTSL, Hilton Hotel, Melbourne, August 25, 2005

Sachs, J. 2007. Learning to improve or improving learning: the dilemma of teacher continuing professional development, in *20th International Congress for School Effectiveness and Improvement* [Online]. Available at: http://www.icsei.net/index.php?id=1713 [Accessed 7 August, 2016]

Sachs, J. 2008. The knowledge society as a trigger for contemporary change in education policy and practice in Sugrue, C. (ed.) *The Future of Educational Change: International Perspectives,* New York, Routledge, pp. 191-203

Sanchez, J. and Salinas, A. 2008. ICT & Learning in Chilean schools: lessons learned. *Computers and Education*, 51: (4), pp 1621-1633

Sandoval, W.A. and Bell, P. 2004. Design-Based Research Methods for Studying learning in Context: Introduction, *Educational Psychology,* 39 (4) pp199-201

Savelsbergh, E.R., Prins, G.T., Rietbergen, C., Fechner, S., Vaessen, B.E., Draijer, J.M. and Bakker, A. 2016. Effects of innovative science and mathematics teaching on student attitudes and achievement: A meta-analytic study, *Educational Research Review,* 19, pp158-172

Sawyer, M. 2012. Everyone wants a slice of Rasberry Pi, *The Guardian, 4 November, Tech* [Online]. Available at: https://www.theguardian.com/technology/2012/nov/04/raspberry-pi-programming-jam-cern [Accessed 14 May 2017]

Saxena, S. 2014. *STEM to STEAM Learning: Learning Science in the 21st Century* [Online]. Available at: http://edtechreview.in/trends-insights/insights/1122-stem-to-steam-learning-learning-science-in-the-21st-century [Accessed 25 July, 2015]

Schleicher, A. 2015. Schools for 21st Century Learners: Strong Leaders, Confident Teachers, Innovative Approaches, in *Key Topic of the 2015 International Summit on the Teaching Profession* [Online]. Available at: http://www.uvm.dk/~/media/UVM/Filer/Om%20os/PDF15/Mar/150326%20OECD%20ISTP%20report_EN.pdf [Accessed 3 April 2015]

Scheffler, F.L. and Logan, J.P. 1999. Computer Technology in Schools: What Teachers should know and be able to do, *Journal of Research on Computers in Education*, 31 (3), pp305-326

Schmidt, D.A., Baran, E., Thompson, A.D., Mishra, P., Koehler, M.J. and Shin, T.S. 2009. Technological Pedagogical Content Knowledge (TPACK): The Development and Validation of an Assessment Instrument for Pre-Service Teachers, *Journal of Research on Technology in Education,* 42 (2), pp123-149

Schon, D. A. 1995. Knowing-in-Action: The New Scholarship Requires a New Epistemology. *Change*. 27 (6) pp27-34

Schul, J. E. 2010. The emergence of CHAT with TPCK: A New framework for researching the integration of desktop documentary making in history teaching and learning, in *The Technology, Humanities, Education and Narrative,* 7, pp9-25

Sci.Dev.Net 24 June, 2016. *Addressing Skills Gaps for Africa's Sustainable Growth* [Online]. Available at: http://www.scidev.net/global/policy/news/africa-sustainable-growth-skillls.html [Accessed 24 July 2016]

Seldon, T. and Cairns, L. 2002. Enhancing Knowledge in Organizations: Developing Capacity and Capability through Learning and Leadership in Leithwood, K. and Hallinger, P. (eds.) *Second International Handbook of Educational Leadership and Administration.* Boston, London: Kluwer Academic Publishers, pp735-744

Shannon, B., Rinaldo, S. B., Tapp, S. and Laverie, D. A. 2011. Learning by Tweeting *Journal of Marketing Education*, 33 (2) pp193-203

Simmie, G. M. 2007. Teacher Design Teams (TDTs) – building capacity for innovation, learning and curriculum implementation in the continuing professional development of in-career teachers, *Irish Educational Studies,* 26 (2) pp163-176

Spring, J. 2008. Research on Globalization and Education. *Review of Educational Research,* 78 (2), pp350-365

Sugrue, C. 2008. *The Future of Educational Change: International Perspectives,* New York, Routledge

Swarts, P. and Wachira, E. M. 2009. *Kenya ICT in Education: Situational Analysis* [Online]. Available at: http://www.eldis.org/go/display&type=Document&id=64494#.UjrGasako0I [Accessed 4 January 2015]

Tai, S. D. 2013. *From TPACK-in-Action Workshops to English Classrooms: CALL Competencies Developed and Adopted into Classroom Teaching* [Online], available at: http://lib.dr.iastate.edu/cgi/viewcontent.cgi?article=4342&context=etd [Accessed 11 January 2014]

Tawil, S. 2012. *Beyond 2015: Perspectives for the Future of Education* [Online]. Available at: http://www.beyond2015.org/sites/default/files/ERF_Discussion_Note_-_Beyond_2015.pdf, [Accessed 5 January 2015]

Teräs, H,. Myllylä, M. and Nevalainen, T 2010. Teacher Training in the Knowledge Society: Web 2.0 And New Professionalism in J. Sanchez & K. Zhang (Eds.), *Proceedings of World Conference on E-Learning in Corporate, Government, Healthcare, and Higher Education 2010* (pp. 1243-1248). Chesapeake, VA: Association for the Advancement of Computing in Education (AACE).

Terpstra, M. 2015. TPACKtivity: An Activity Theory Lens for Examining TPACK Development, in Angeli, C. and Valanides, N. (Eds), *Technological, Pedagogical, Content Knowledge: Exploring, Developing and Assessing TPCK*, pp63-88

The Design-based Research Collective 2003. Design-Based Research: An Emerging Paradigm for Educational Inquiry, *Educational Researcher,* 32 (1), pp5-8

The New Media Consortium and the Consortium for School Networking 2016. *The NMC/CoSN Horizon Report: 2016 K-12 Edition* [Online]. Available from NMC/CoSN at: https://www.nmc.org/publication/nmc-cosn-horizon-report-2016-k-12-edition/ [Accessed 14 May 2017]

Trucano, M,, 2005. *Knowledge Maps: ICTs in Education*, Washington, DC, *info*Dev / World Bank.

Trucano, M. 2017. *Linking up with Enlaces (Chile)* [Online]. Available from World Bank Edutech Blog at: http://blogs.worldbank.org/edutech/linking-up-with-enlaces-chile [Accessed 5 March 2017]

UN 2002. *UN Millennium Project* [Online]. Available at: http://www.unmillenniumproject.org/ [Accessed 24 July 2016]

UN 2015. *Sustainable Development Goals: 17 Goals to Transform Our World* [Online]. Available at: http://www.un.org/sustainabledevelopment/sustainable-development-goals/ [Accessed 8 March 2017]

UNESCO 2005. *Towards Knowledge Societies* [Online]. Available at: http://unesdoc.unesco.org/images/0014/001418/141843e.pdf [Accessed 3 April 2015]

UNESCO 2008, 2011. *ICT Competency Framework for Teachers* [Online]. Available from UNESCO at: http://www.unesco.org/new/en/unesco/themes/icts/teacher-education/unesco-ict-competency-framework-for-teachers/ [Accessed 9 January 2014]

UNESCO 2012. *Fact Sheet: Education in Kenya*.[Online]. Available at: http://www.unesco.org/new/fileadmin/MULTIMEDIA/HQ/ED/pdf/EDUCATION_IN_KENYA_A_FACT_SHEET.pdf [Accessed 7 January 2015]

UNESCO 2013. *ICT in Education Policy, Infrastructure and ODA Status in Selected ASEAN countries* [Online]. Available from UNESCO Bangkok at: http://www.unescobkk.org/fileadmin/user_upload/ict/e-books/ICT_in_Education_Policies__Infrastructure_and_ODA.pdf

UNICEF 2011. *Child Friendly School Manual outlines a brighter future for Kenyan children through education* [Online]. Available at: http://www.unicef.org/mdg/kenya_57616.html and http://www.unicef.org/publications/files/Child_Friendly_Schools_Manual_EN_040809.pdf, accessed 6 March 2016

University of Cambridge, Faculty of Education 2015. *The OER4Schools Professional Learning Resource* [Online]. Available at: http://oer.educ.cam.ac.uk/wiki/OER4Schools [Accessed 10 January 2015]

Unwin, T. 2004. Towards a framework for the use of ICT in teacher training in Africa. *Open Learning: The Journal of Open and Distance Education* [Online], 20, pp 113-129, available from: http://www.gg.rhul.ac.uk/ict4d/ict%20tt%20africa.pdf [Accessed 15 January 2015]

Voogt, J. and Pelgrum, H. 2005. ICT and Curriculum Change, *Human Technology*, 1 (2), pp157-175

Voogt, J. and Roblin, N. P. 2010. *21st Century Skills: Discussion Paper* [Online]. Available from NCVER at: http://www.voced.edu.au/content/ngv%3A56611 [Accessed 27 July 2016]

Voogt, J. and Roblin, N. P. 2012. A comparative analysis of international frameworks for twenty first century competences: implications for national curriculum policies. *Journal of Curriculum Studies*, 44(3), 299–321

Vygotsky, L.S. 1978 *Mind in Society: The Development of Higher Psychological Processes*, Cambridge, Massachusetts, London, Harvard University Press

Wang, F. and Hannafin, M. J. 2005. Design-Based Research and Technology-Enhanced Learning Environments, *Educational Technology Research and Development,* 53 (4), pp 5- 23

Wanzala, O. 2016. Kenyans root for curriculum focused on imparting skills in learners*, Daily Nation, March 31,* [Online]. Available at: http://www.nation.co.ke/news/School-will-never-be-the-same-again/-/1056/3140144/-/i8lju2z/-/index.html [Accessed 23 July, 2016]

Whitehead, J. and McNiff, J. 2006. *Action Research Living Theory*, London, Sage Publications

Williams, P. J. 2011. STEM Education: Proceed with caution, *Design and Technology Education: An International Journal,* 16 (1) pp 26-35

Williams, A. and Katz, L. 2013. The Use of Focus Group Methodology in Education: Some Theoretical and Practical Considerations, *International Electronic Journal for Leadership in Learning* 5 (3)

Wilson, A. and Moffat, D. 2010. Evaluating Scratch to introduce younger schoolchildren to programming, *ScratchEd – learn, share, connect* [Online]. Available at: http://scratched.gse.harvard.edu/resources/evaluating-scratch-introduce-younger-schoolchildren-programming [Accessed 14 May 2017]

World Economic Forum, Bailey, A., and Kaufman, E. 2015.*Industry Agenda: New Vision for Education: Unlocking the Potential of Technology* [Online]. Available at: http://www3.weforum.org/docs/WEFUSA_NewVisionforEducation_Report2015.pdf [Accessed 12 July, 2016]

Xenofontos, N., A. Fiakkou, A., Hovardas, T., Zacharia, Z., Anjewierden, A., L. Bollen, L. and Pedaste, M. 2016. Examining the Added Value of the Use of an Experiment Design Tool among Secondary Students when Experimenting with a Virtual Lab, in *Proceedings of the 8th International Conference on Education and New Learning Technologies*, EDULEARN2016, Publication Publisher: IATED, Barcelona, Spain, 2016 [Online]. Available at: https://library.iated.org/view/XENOFONTOS2016EXA [Accessed 14 May 2017]

Yamagata-Lynch, L.C. 2003. Using Activity Theory as an Analytical Lens for Examining Technology Professional Development in Schools. *Mind, Culture and Activity* 10 (2), pp100-119

Zevenbergen, R. and Lerman, S. 2007. Pedagogy and Interactive Whiteboards: Using an Activity Theory Approach to Understand Tensions in Practice, in *Proceedings of the 30th Annual Conference of the Mathematics Education Research Group of Australia* [Online],. Available at: http://www98.griffith.edu.au/dspace/bitstream/handle/10072/18685/49294_1.pdf?sequence=1[Accessed 6 March, 2016]

Zhang, Y. and Wildermuth, B. M. 2006. *Qualitative Analysis of Content* [Online], available at: https://www.ischool.utexas.edu/~yanz/Content_analysis.pdf [Accessed 9 July 2016]

APPENDICES

Appendix 1: SIPSE Modules and Design

Appendix 1.1: SIPSE Modules

Five modules covering Technology Literacy (3 modules) and Knowledge Deepening (2 modules) ICT Teacher Competency levels

Technology Literacy Modules 1, 2 and 3

<table>
<tr><td colspan="3">

Module 1 ICT Use in Didactic Teaching

ICT Teacher Competencies

- Teachers describe how **didactic teaching** with ICT can be used to support students' acquisition of STEM subject matter Knowledge **(TL.3.a.),**
- Teachers **i**ncorporate appropriate ICT activities into lesson plans so as to support students' acquisition of STEM subject matter knowledge**. (TL.3.b.)**

</td></tr>
<tr>
<td>In this unit you will learn about</td>
<td>To meet the learning intentions and objectives you will</td>
<td>The ICT components you will focus on are</td>
</tr>
<tr>
<td>

How didactic teaching with ICT can be used to support students' acquisition of STEM subject matter knowledge
Improving your skills in basic software of word processor or presentation or spreadsheet
Exploring ICT tools for 'practice and drill' in your planning activities for your subject teaching
Activity templates for introducing technology in your practice and how these can be used alongside your lesson teaching in STEM

</td>
<td>

Explore the use of ICT practice and drill activities to support content and pedagogy strategies in a STEM didactic lesson (introduction/ main activities/ assessment)
Complete an activity template for a practice and drill that has a clear link to a STEM topic objective that you are teaching
Do this activity in the classroom
Share the activity with your subject teachers in your school and with your subject teacher group in the SIPSE group workspace

</td>
<td>

ICT basic – familiarization with basic uses of word or presentation or excel software; Internet use
ICT exploration – Practice and drill exercises with word or presentation or excel or specialized software

</td>
</tr>
</table>

Module 2 ICT and STEM Curriculum Standards

ICT Teacher Competencies

- Teachers should be able to match specific curriculum standards to particular software packages and computer applications and describe how these standards are supported by these applications. **(TL.2.a**)
- Teachers help students acquire ICT skills within the context of their subjects or courses. **(TL.2.b.)**

In this unit you will learn about	**To meet the learning intentions and objectives you will**	**The ICT components you will focus on are**
• Finding, evaluating, organizing and adapting the right ICT resources (e-content) to meet your teaching and learning requirements in your subject teaching • Finding and evaluation of open education software using the GESCI criteria for software evaluation • Developing student writing skills to promote sharing and communication of ideas • Exploring and reviewing Mathematics, Science, and Language software education software packages suitable for promoting problem-based and interactive learning in your subject teaching • Using **ICT resources in the didactic lessons to promote interactive learning** and engage students in using the resources • Using different **questioning techniques** to promote interactive learning with ICT in your didactic lessons • Identifying ICT resources appropriate to the **different characteristics and needs** of your learners • Exploring the use of presentation software to promote interactive activates and student learnin	• Practice using presentation, evaluating and using e-resources and using effective questioning techniques • **Plan activities using presentation, e-resources and questioning techniques** to increase student participation and interaction in your subject teaching. You can plan your activities for any part of the didactic lesson – teacher exposition, students' activities or student and teacher review. • Complete an activity template for your presentation & questioning activity that has a clear STEM subject learning objective • **Do this activity** in the classroom • **Reflection on your activity** using your journal (and revise if necessary)	• **ICT exploration –** presentation software - basic & advanced • **Internet –** search, retrieve and evaluate e-resources

Module 3.1 ICT in the Classroom and Computer Lab

ICT Teacher Competencies

- Teachers integrate the use of a computer laboratory into on-going teaching activities. **(TL.5. a)**
- Teachers are able to identify key characteristics of classroom practices and specify how these characteristics serve to implement national policies (**TL.1.a.**)

In this unit you will learn about	To meet the learning intentions and objectives you will	The ICT components you will focus on are
• The **use of computers in a computer lab** setting • Brainstorming ideas on **parts of subject teaching that can benefit** from ICT lab environment • Developing **ideas for the use of group work** in computer lab settings • Exploring the **use of simulation tool** to promote **interactive learning, discussion and thinking**	• In your subject group plan a simulation and computer lab lesson for a STEM didactic lesson (introduction/ main activities/ assessment) • Complete an lesson plan template for a technology enhanced simulation activity that has a clear STEM subject learning objective • **Conduct the lesson** in the classroom and/ or computer lab • **Reflect on the lesson** (and revise if necessary) to ensure maximum learning by the students • Share the plan with STEM teachers in your school and with the SIPSE community online	• **ICT basic –** Developing simulations on presentation and spread sheet simulation software • **ICT exploration –** Exploring the use of advanced simulation software in STEM teaching and learning

Module 3.2 National Policies and their Impact on Education

ICT Teacher Competencies
Teachers are able to identify key characteristics of classroom practices and specify how these characteristics serve to implement national policies (**TL.1.a**.)

In this unit you will learn about	To meet the learning intentions and objectives you will	The ICT components you will focus on are
• how to link national and school vision and objectives for ICT in education and classroom practices • how to support national, school and SIPSE objectives in school planning and classroom practices • how to use the SIPSE school criteria framework to do an ICT SWOT analysis of your school • activities with ICT tools for navigating and downloading national documents & resources for ICT policy	• conduct an **ICT Review & SWOT analysis of school** to share with staff and management • brainstorm **ideas on school and classroom practices** to support national, school and SIPSE objectives • share your ideas with your subject teachers in your school and your subject group online • **develop your portfolio** with examples of: • your activity & reflection on trialling presentation or other ICT tools in your classroom activities • your presentation of school ICT Review SWOT analysis	• **ICT basic –** familiarization with basic uses of word or presentation or excel software • **ICT advanced –** use of presentation software – charts and videos/ audio etc – • **Think about how to use** presentation software to present your school ICT SWOT analysis

Knowledge Deepening Modules 4 and 5

Module 4.1 Problem-Based Learning and ICT in the Classroom

ICT Teacher Competencies

- Teachers **identify or design complex, real-world problems** and structure them in a way that incorporates key subject matter concepts and serves as the basis of student projects. **(KD.3.b.)**
- Teachers place and organize computers and other digital resources within the classroom so as to support and reinforce learning activities and social interactions. **(KD.5.a)**

In this unit you will learn about	**To meet the learning intentions and objectives you will**	**The ICT components you will focus on are**
• How **problem-based learning & teaching with ICT** can be used to support students' acquisition of STEM subject matter knowledge • Exploring **brainstorming and group work organization strategies** to get the most from problem-based learning • Managing and creating **a positive classroom environment** for ICT use • Using **Concept Mapping software** to promote problem-based learning	• Plan a **problem-based learning activity with brainstorming, group organization and concept mapping strategies** to engage students in observations, discussions and questions in order to solve a problem • Complete an activity template for a problem-based learning and simulation activity that has a clear STEM subject learning objective • **Do this activity** in the classroom • **Reflect on this activity** (and revise if necessary) to ensure maximum interaction by the students on problem solving and discussions • Share the activity with STEM teachers in your school and with the subject teachers in your SIPSE community online	• **ICT exploration –** Exploring productivity tools to create concept maps and mind maps • **ICT resource development –** Developing concept maps and / or mind maps for us in classroom practice

Module 5 Project-Based Learning

ICT Teacher Competencies

Teachers describe how collaborative, project-based learning and ICT tools can support student thinking and social interaction, as students come to a deeper understand key concepts, processes, and skills in the subject matter and their application and use to solve real world problems. (KD.3.a.)

In this unit you will learn about	**To meet the learning intentions and objectives you will**	**The ICT components you will focus on are**

• How **project-based learning & teaching with ICT** can be used to support students' acquisition of STEM subject matter knowledge
• Guidelines for setting up **project and cooperative learning opportunities** in the classroom
• Introduction to web quests planning preparation, organizing of groups and resources and assessment
• Using **Webquest software** to stimulate and scaffold project development and exploration
	• Plan a **project with cooperative learning opportunities and Webquest software** to engage students in observations, discussions and questions in order to engage in a structured inquiry
	• Complete an **planning template for a project process activity** that has a clear STEM subject learning objective – where the project process involves teaching and learning for
	    ○ posing productive questions
	    ○ finding resources/ organizing groups
	    ○ interpreting information
	    ○ reporting finings
	• **Do this activity** in the classroom
	• **Reflect on this activity** (and revise if necessary) to ensure maximum interaction by the students on project process
	• Share the activity with STEM teachers in your school and with the subject teachers in your SIPSE community online
		• **ICT exploration** – exploration tools to create Webquest resource for project-based learning
		• **ICT resource development –** developing a Webquest resources for project development in your subject teaching

Appendix 1.2: SIPSE Module Design

Course Module Structure – 4 activities leading to TPACK & ICT-CFT-in-Practice

Building capacity for innovative use of ICT in STEM - 4 activities in each module		
Introductory Activity	**Content Knowledge** Case Study Activities	**Exemplary Curriculum Materials** --- Participants see & review ICT enhanced STEM Lesson Plans
T&L Strategies Activity	**Pedagogy Knowledge** Building teaching and learning strategies	**Pedagogical Discussion & Exploration** --- Participants discuss & explore traditional & new pedagogical strategies to support STEM
ICT Practice Activity	**Technology Knowledge** Building ICT basic and advanced skills	**ICT Tool Demonstration & Practice** --- With examples of instructional use
Classroom Practice Activity	**TPACK-in-Practice** Applying and infusing 'technology' to support 'pedagogy' and 'content' in classroom practice	**Classroom Application** --- Teachers create activities & lessons that demonstrate ICT use in STEM teaching and learning. Teachers try out lesson, observe each other's lessons, reflect on practice and make recommendations and suggestions for improving practice.

Adapted: Jaipal & Figg (2012)

Appendix 2: Design Based Research Matrix

Research Questions	**DBR Approach** ICT-CFT, Activity Theory and TPACK Lenses	**Processes and Outputs**
Research Question 1: What is the object of ICT integration perceived by head teachers and teachers during the two cycles of the SIPSE pilot programme?	Context and literature review **Activity Systems Lens** • Individual and group interviews with head teachers/ teachers • Teacher Questionnaires *September 2014/ February 2015/ February 2016*	**Tracking the object of ICT integration** • over 2 cycle of ICT-CFT-TPACK-in-practice programme implementation • in the context of classroom, school and education learning eco-systems
Research Question 2: What are the characteristics of teacher design for ICT use in STEM teaching and learning mid-way through the SIPSE pilot programme, as evidenced in their approach to problem-based activities?	ICT-CFT Problem-based Learning Activities **TPACK Lens** • Peer-to-peer observation notes • Focus group discussion *September 2014*	**Design conversations** on TCK applications in STEM classroom practice
Research Question 3: What are the characteristics of teacher design for ICT use in STEM teaching and learning at the end of the SIPSE pilot programme, as evidenced in their approach to project-based activities?	ICT-CFT Project-based Learning Modules **TPACK Lens** • Peer-to-peer observation notes • Focus group discussion *February 2015*	**Design conversations** on TPK applications in STEM classroom practice
DBR Product Question: How can the findings from applying the SIPSE pilot programme inform future models of teacher professional development for ICT in practice?	**TPACKtivity lens** • School and classroom activity system object of ICT integration • TPACK teacher design mappings • ICT-CFT professional learning eco-system *September 2014/ February 2015/ February 2016*	**Research Product and Knowledge Management** • ICT-CFT-TPACK-in-practice professional development model • Professional Learning eco-system – vision and action from national to local levels

Appendix 3: Data Collection Instruments – Activity Theory Lens

Instruments: Activity Theory/ Activity Systems Schedule Set – Interview Schedule with Focus Group Discussion & Questionnaire formats

Appendix 3.1: Head Teacher AT/AS Interview Schedule (F2F & Skype)

1. **General:**
    a. Tell me about your school, how many students, boys/girls, how many teachers, how many departments, what are the subjects, are there any school partnerships?
    b. Does the school have a particular focus in its curriculum?
    c. Are there any particular issues faced by the school?

2. **Examine the activity system domains of ICT use in school**
    a. **Objectives** –
    Does the school have a policy/vision/ plan for the role of ICT in teaching and learning? If yes, could you describe your policy / vision / plan?
        - Are the objectives of that policy/ vision/ plan directly/ indirectly linked to the objectives of national vision/ policies for ICT integration - if so, how are they related?
        - Have the objectives changed since the SIPSE teacher development programme was introduced in the school?
        - How have they changed?

    b. **Subject/s** –
    Who is involved in ICT use in the school?
        - Are there different roles for who is involved in ICT (principal, head of department and ICT dept, the STEM teachers)?
        - Whose role dominates the objectives for ICT use in the schools? Why?

    c. **Tools** –
    What resources (ICT/non-ICT) are available for the SIPSE programme in the school?[34]
        - What resources are needed?

    d. **Rules and regulations** –
    What are the rules and beliefs about teaching & learning in the school?
        - What are the formal / informal regulations that have to be followed to meet the objectives of ICT integration in the school?

    e. **Roles and responsibilities** –
    What specific responsibilities do the actors in your institution assume to achieve the school goals for ICT integration?

[34] **ICT Tools:** Computer lab, computer peripherals (camera , printer, photocopiers, speakers etc.), laptops, projectors, teachers personal devices, SIPSE e-learning and m-learning platforms, CDs, internet, email, School website, STEM subject content database , Availability of peripherals/ Availability of software types/ availability of software for subject teachers / administration
Non-ICT tools: pedagogical strategies, subject content curriculum, assessment, creativity & innovation projects, administrative -system management (register/ reports/correspondence) and teaching functions

- Are your teachers comfortable with using computers? How many of your teachers use/do not use the computers/ laptops / projectors on a regular basis?

f. **Community** –What institutions / group of institutions do you work with to meet the school goals for ICT integration?

3. **Most Significant Change**
   - From your point of view, can you tell a story which describes the ‘most significant change or impact’ in your school since the SIPSE project was introduced?
   - What’s different? Who was impacted?
   - How did SIPSE contribute to the change/ impact?

Thank you

Appendix 3.2: Teacher AT/ AS Interview Schedule (F2F, Skype & Group)

1. **General**
    a. What subject area/class/level are you lecturing/teaching?
    b. How many students/pupils are there in your class?
    c. How long have you been lecturing/ teaching?

2. **Examine the activity system domains of the SIPSE ICT programme implementation**
    a. **Goals** –
    What are your ideas and beliefs about teaching and learning in your subject area (Science, Technology, English and Mathematics)?
    - What is your objective for using ICT in your Science, Technology or English or Mathematics teaching?
    - How has your objective for using ICT changed since you started in the SIPSE course?
    - What are the most important aspects of the SIPSE teacher development course that have encouraged you to use ICT in your personal/professional practice?
    - Do you plan to go on using ICT in your teaching?

    b. **Tools** –
    What are the non ICT/ ICT tools that you use in the teaching/learning process?
    (admin tools, practice and drill, presentations, word, spreadsheets, simulations, the internet, laptops, projectors, mobile phones)
    - What methods do you apply when using ICT in teaching and learning?
    (pedagogical strategies to promote discussion, different levels of questioning, collaborative learning, group work to support didactic teaching)
    - What difficulties do you encounter when using ICT?

    c. **Rules and regulations** –
    Are there rules set by the institution/ school about using ICT in programmes/classroom practice?
    - Standard setting –what are the criteria that you use when evaluating learning of students?
    - Do the criteria change in the classes where you use ICT? Do you develop new criteria for these classes?
    - Do the national examinations influence how you use ICT and what you cover in course provision/ in the classroom?

    d. **Roles and responsibilities** –
    What kinds of different roles/ responsibilities do you/ your pupils assume in class when using ICT?
    - If you went into a classroom of a good SIPSE teacher using technology in their STEM teaching, what would you see?
    - Does the school administration support you in the use of ICT in teaching and learning processes?
    - How does the school support ICT use in programmes/ classroom work to function?

    e. **Community** –

What kind of collaboration is there among teachers in the school (with other schools) about SIPSE use of ICT in teaching and learning?

3. Most Significant Change

- From your point of view, can you tell a story which describes the ‘most significant change or impact’ in your practice since using ICT in the SIPSE project?
- What’s different? Who was impacted?
- How did SIPSE contribute to the change/ impact?

Thank you

Appendix 3.3: Teacher AT/ AS Questionnaire

Teacher Questionnaire

Details: School and Teacher Names/ Contacts		
Name of School	**Names of Teachers**	**Contacts**

General Introduction and Background Information		
Main Question	**Probes**	**Responses**
General What subject area/class/level are you lecturing/teaching?	1. How many students/pupils are there in your class? 2. How long have you been lecturing/ teaching?	

Part 1: Use of ICT in teaching and learning		
Main Question	**Probes**	**Responses**
1. Goals What are your ideas / approaches about teaching and learning in your subject area (Science, Technology, English and Mathematics)?		
	• What is your objective for using ICT in your Science, Technology or English or Mathematics teaching?	
	• How has your objective for using ICT changed since you started in the SIPSE course?	
	• What did you find most valuable about the SIPSE professional development modules?[35]	
	• Do you plan to go on using ICT in your teaching? If so, in what ways?	
	• What general activity ideas or lesson planning activity ideas from the modules did you bring back to your classroom practice?	

[35] The modules were:

- **Module 1** - ICT & Didactic teaching – introducing word, presentation, spreadsheets & discussion techniques, focus on practice & drill
- **Module 2** – ICT & STEM curriculum – ICT & interactive learning, e-resources and questioning techniques for STEM, focus on presentation
- **Module 3** - ICT & Classroom Organization – computer lab and classroom , group organisation, simulation tools
- **Module 4.1** - ICT & Problem-based learning– problem-based strategies, question types for higher order thinking, focus on concept mapping
- **Module 4**.2 – ICT & project-based learning – webquests, - Introduction, tasks, process, resources, guidelines, evaluation, conclusion

Part 1: Use of ICT in teaching and learning		
Main Question	**Probes**	**Responses**
2. Tools What are the non ICT/ ICT tools that you use in the teaching/learning process? (admin tools, practice and drill, presentations, word, spreadsheets, simulations, the internet, laptops, projectors, mobile phones)		
	• What non-ICT tools - methods do you apply when using ICT in teaching and learning? (pedagogical strategies to promote discussion, different levels of questioning, collaborative learning, group work to support didactic teaching)	
	• How often do you use ICT to teach SME subjects – please indicate which of the following: o Every day? o Once a week? o Once a month? o Never?	
	• What kinds of barriers have you encountered with using technology in your Science, Technology, English and Mathematics after the training?	
	• How have you addressed these challenges	
3. Rules and regulations Are there rules set by the institution/ school about using ICT in programmes/classroom practice? - that influence how you use ICT in practice?		
	• Standard setting –what are the criteria that you use when evaluating learning of students?	
	Do the criteria change in the classes where you use ICT? Do you develop new criteria for these classes?	
	Do the national examinations influence how you use ICT and what you cover in course provision/ in the classroom?	
4. Roles and responsibilities What kinds of different roles/ responsibilities do you/ your pupils assume in class when using ICT?		
	Training Support Role • How do you see that the ICT-STEM training assisted you in integrating technology in your STEM subjects teaching? Is it changing your role as a teacher - explain how it is changing your role?	
	School Support Role • Does the school administration support you in the use of ICT in STEM? Explain	

Part 1: Use of ICT in teaching and learning		
Main Question	**Probes**	**Responses**
	• How does the school support ICT use in programmes/ classroom work to function?	
	Technical support Role • Have you encountered difficulties in using the laptop and project technology in your teaching?	
	Student role • How do you think the ICT SIPSE training and programmes have benefitted your students' learning? • What kinds of different responsibilities do you see your students doing in your STEM classes where you are using ICT? • What can you tell about how students use technology outside class or school hours?	
5. Community	What kind of collaboration is there among teachers in the school (with other schools) about SIPSE use of ICT in teaching and learning?	

Adapted:

- Davies, R, and Dart, J. (2005) The 'Most Significant Change' Technique [Online], available at: http://www.mande.co.uk/docs/MSCGuide.pdf, accessed 11 July 2015
- Lim, C.P. and Hang, D. (2003) An activity theory approach to research of ICT integration in Singapore schools. *Computers and Education,* 41, pp49-63.
- Mwanza, D. and Engeström, Y. (2003, November 7–11). Pedagogical adeptness in the design of eLearning environments: Experiences from Lab@Future project, in Robertson, I. (2008) Sustainable e-learning, activity theory and professional development. *IN: Proceedings ascilite Melbourne 2008, November 30 – December 3* [Online], available from: http://www.ascilite.org.au/conferences/melbourne08/procs/index.htm,accessed 11 July 2015

Appendix 4: Data Collection Instruments – TPACK Lens

Instruments: TPACK Observation and Focus Group Discussion Schedules

Appendix 4.1: TPACK Peer-to-Peer Lesson Observation Schedule

Part 1: Pre-Lesson Review: Background information

1. Name (s) of observer (s)	
2. Name of teacher	
3. Name of school	
4. Name of County / District	
5. Class or form	
6. Subject being taught	
7. No of students in the class	
8. No of Boys	
9. No of Girls	
10. Observation Date	
11. Observation Time	

1. **What are the teacher's webquest unit lesson objectives in the lesson?** : (*If possible, speak with the teacher before the observation begins and complete this section with the following information: What is the teacher planning to do? How does the webquest lesson fit in with the unit? Are there are particular outcomes the teacher is hoping for?)*

2. **What are the teacher's classroom arrangements for the webquest lessons?** *(Draw or describe the physical arrangement of the classroom. Also what happens as the lesson progresses – what pedagogical strategies does the teacher adopt throughout the lesson – whole class, group work, same task/ different task group work, etc)*

3. **What technology resources are present in the classroom?** (*Describe the technology resources (ICT and non-ICT) present in the classroom and include the number of each)*

Part 2: Lesson Observation Notes

In this section, please take detailed notes in real time as you observe classroom activities.
The following questions serve as guidelines for what you will document during the classroom observation. For each topic/question, please note what you observe in the left-hand column; you can use the right-hand column to note your ideas about what you think.

Structure and content of the webquest unit lessons (CK)

- Describe the structure of the webquest unit lesson that you observe. What is happening in the classroom? What are the teacher and the students doing?
- Does the teacher present some kind of introduction 'hook' (*story or problem or information or brainstorming*) to engage the students on the webquest topic? Does the teacher introduce the webquest task?
- Does the teacher provide appropriate information and guidelines for the weqbuest group learning process being introduced?

What you see	What you think - works well/ less well

Use of technology (ICT/ non-ICT) to support webquest content (TCK)

- What technologies were being used (*spreadsheet or presentation or word or concept mapping or other*)?
- What web quest ICT resources were being used (*links to websites or news stories or articles or problems on the webquest task; use of the laptop by students; use of the computer lab; use of mobile phones to conduct research, make presentations* etc.)
- What non-ICT technologies were being used? (*worksheets, blackboard, chalk, text books, library books group work tasks, copy book pages, manila paper, assessment rubrics*).
- How is the technology being used? What did the teacher do with the technology? What did students do with the technology? How does technology shape the way that students interact with the webquest to produce their presentation?
- Are teachers or students experiencing difficulties in their use of the technology/device? Are they able to troubleshoot? How does the technology facilitate interaction among students? What kinds of webquest products did students produce?

What you see	What you think - works well/ less well

Use of technology & pedagogical strategies (TPK)

- What levels of questioning does the teacher engage the students with (*remembering, understanding, analysing, applying, evaluating & creating type questions*)? Try to capture examples of the type of questions teachers ask students and how students respond, as well as the questions students ask teachers and the teacher's responses.
- What group work strategies does the teacher use with the students to produce the webquest (*same task group work webquest/ different tasks group work webquest*)?
- How does the teacher engage the students on the different steps of the webquest project work (*introduction, define task, process, guidance, product presentation, rubric evaluation, conclusion and follow-up*)? How does the technology (ICT and non-ICT) support the project-based learning strategies?

What you see	What you think - works well/ less well

Application of technology, pedagogy and content knowledge (TPACK)

- How do the teachers pedagogical strategies (*project-based learning, questioning levels, group work organization for collaborative learning*) and choice of technology (*presentation, web links, library books computer lab, text books, manila paper*) fit together with the content topic?
- How are the students and teachers using the technology to interact with content in new ways? Does the technology give teachers and students access to instructional resources and/ or content information?
- Does the technology activity allow students to build or practice higher order thinking skills (*i.e. problem solving, reasoning, synthesizing information, creating content*)?

What you see	What you think - works well/ less well

Part 3: ***Student Group Webquest Presentation Evaluation Rubric***

Name of School____________________; Teacher ______________;
Student Group ______________; Name of Observer _______________

Product Assessment Criteria	Excellent 16 – 20	Good 11 – 15	Satisfactory 6 - 10	Fair 1 - 5	Score	Comments
Organization	Presentation is well organized, neat and communicates very clearly the topic information	Presentation communicates clearly topic information – but needs spoken explanation	Presentation communicates quite clearly topic information – but needs a lot of spoken explanation	Presentation does not clearly communicate the topic information – even with spoken explanation		
Quality of content	Answers all webquest questions very well and contains other interesting facts or conclusions	Answers all webquest questions well	Answers some webquest questions well	Answers very few webquest questions or none at all		
Quality of group presentation	Presentation visuals and effects are very effective and improve the content – and do not distract from the content	Visuals and effects in the presentation are effective – and do not distract from the content	Visuals and effects in the presentation are quite effective – and do not distract from the content	Visuals and effects in the presentation are not effective – and they are distracting from the content		
Quality of group research	Group can organize, analyse and synthesize information from a variety of sources	Group can organize, analyse and with help can synthesize information from a variety of sources	Group can with help organize and analyse information from a variety of sources	Group has difficulty to organize and analyse information even with help		
Quality of group communication	Group members interact, collaborate and work effectively together to produce an original project	Group members with some teacher guidance can work collaboratively and effectively together to produce an original project	Group members with a lot of teacher guidance can work collaboratively and effectively together to produce an original project	Group members have difficulty to work collaboratively and effectively together even with teacher guidance		
Total Marks						

Adapted: Dodge, B. and Pickett, N. (2007) *Creating rubrics for web lessons*, available at: http://webquest.org/sdsu/rubrics/weblessons.htm

PART 4: Complete *TPACK Teacher Lesson Self-Review*

PART 2: Teacher's general reflection comments
Content: What do you think your pupils learned from the webquest unit lesson? How can you tell? Were there any unexpected things that happened? **Teacher's reflections:**
Technology: What resources did you use (both ICT and non-ICT) for the webquest? Do you think your use of ICT resources in your webquest lesson contributed to your students' understanding of the webquest concepts? How? **Teacher's reflections:**
Pedagogy: Which pedagogical strategies did you use - 'questioning' or 'collaborative group work' or 'webquest tasks, process, guidelines, product, evaluation and conclusion' to support the curriculum learning objectives? What learning experience did your students get out of the webquest activity? How can you tell? **Teacher's reflections:**
Technology pedagogy and content knowledge: Does the content, pedagogy and technology 'fit' together to support the webquest curriculum learning objectives? **Teacher's reflections:**

Appendix 4.2: Focus Group Discussion Schedule

Post Lesson Focus Group Discussion Guidelines: Lesson Teacher, Teacher Observers and Researcher

Main observation areas	**General Questions**	**Probing questions**
1. Pedagogy and Content (PCK): • Lesson topic learning objectives, • Hook (*story or problem or information*), • Web quests steps – intro, task, process, guideline, product, evaluation & conclusion	**What did you see?** **What did you think? (worked well/ less well)?**	How do you see the webquest project strategies supporting the lesson topic objectives?
2. Technology & Content (TCK): • ICT (*presentation or word or spreadsheets or other*) • Non-ICT (*worksheets, blackboard, texts, creative/ innovative webquest tasks/ projects*), *rubric assessment,*	**What did you see?** **What did you think? (worked well/ less well)?**	How and why do you see the webquest tools (ICT and non-ICT) supporting the lesson content and processes?
3. Technology & Pedagogy (TPK): • Questioning (*remembering understanding, analysing, applying, evaluating and creating type questions*), • Group work (cooperative group work strategies, self-assessment and management), • Project-based webquest (*intro, task, process, guideline, product, evaluation & conclusion)* • Technology (ICT & non-ICT)	**What did you see?** **What did you think? (worked well/ less well)?**	How and why do you see the webquest tools (ICT and non-ICT) supporting the instructional strategies of the lesson?
Observation Areas	**What did you see?**	**What did you think?** **Worked well/ less well**

TPACK APPLICATION Technology (*presentation, web links, library books computer lab, text books, manila paper*), pedagogy (*project-based learning, questioning levels, group work organization for collaborative learning*), and content (*webquest topic*)	**What did you see?** **What did you think? (worked well/ less well)**	How and why do you think the learning goals, instructional strategies, and technologies used in this lesson all fit together? Explain why or why not they fit?

Final Remarks and recommendations

a. What is the overall learning by lesson teacher, teacher observers, researcher from the lesson?
b. What are the recommendations for applying the learning in next lessons?

Researcher, Lesson Teacher and Teacher Observers Concluding Remarks and Recommendations

Adapted:

- "TPACK Observation Assessment Instrument" accessed from College of William & Mary, School of Education [Online], available at: http://activitytypes.wmwikis.net/Assessments
- INTEL (2010) *Guide to Monitoring eLearning Programs: INTEL Education Transformation Research Standard Research Design and Toolkit* [Online], available at: http://download.intel.com/education/transformation/US_EdTrans_ResearchToolkit.pdf, accessed 16 September, 2013

Appendix 5: Coding and Themes

An overview of deductive and inductive coding matrices and frameworks; mapping of thematic prevalence shaping ICT-CFT-TPACK in practice

Appendix 5.1: Deductive Codes - Activity Theory

Activity Systems: A categorization matrix for data analysis

Category	Coding Descriptors
Object of ICT integration	Problem space that head teacher and teacher subjects are working on and the goals they are seeking through use of technology
Subject	The individual (or smaller group) who is acting in the environment toward the object
Tools & Resources	Mediating tools that allow head teacher and teacher subjects to pursue objects. The tools can be conceptual (principles, frameworks, beliefs about and experiences in teaching and learning) and practical (textbooks, computer hardware and software, paper and pen)
Rules & Regulations	Conventions/ expectations that constrain/ influence activities in the classroom, school or organization learning system – explicit & implicit
Community of Practice	Group with shared interest in the outcomes
Division of Labour	Role of teacher & learner that they assume when carrying out the activity

Adapted: Yamagata-Lynch 2008, Engeström *et al.,* 2013; Terpstra, 2016

Appendix 5.2: Deductive Codes - TPACK

TPACK: A categorization matrix for data analysis

Category	Definition	Coding Descriptors
Pedagogical knowledge (PK)	An understanding of strategies and methods that be used to facilitate teaching practice and student learning	PK - Demonstrating abilities / the ways teachers use / consider appropriate teaching methods
Content Knowledge (CK)	An understanding of a subject matter in which the knowledge of concepts, theories and structures of a discipline are included	CK – Demonstrating abilities/ the way teachers show a deep understanding of the structure and content of the selected topic
Technological Knowledge (TK)	An ability to use and master a variety of digital technologies to accomplish a task	TK - Demonstrating abilities / the ways teachers tap technology knowledge to use different technologies to create digital artefacts
Pedagogical Content Knowledge (PCK)	An understanding of how represent subject content with suitable teaching methods	PCK - Demonstrating abilities / the ways teachers teach content in consideration of students' needs or backgrounds
Technological Pedagogical Knowledge (TPK)	An ability to evaluate advantages and limitation when using technologies to teach specific learning activities	TPK – Demonstrating abilities / the ways teachers use technology appropriately based on students learning needs/ how pedagogy can be adapted to meet unique content and skills of different subject areas
Technological Content Knowledge (TCK)	An ability to identify topics with high need for technology and to represent the content using suitable technology	TCK 1. Demonstrating abilities / the ways teachers identify the necessity of using technology in the selected topic 2. Demonstrating abilities / the ways teachers apply appropriate technology to present topics that are difficult to teach using traditional methods
Technological Pedagogical Content Knowledge (TPCK)	An understanding emerges from interaction among the knowledge of technology, pedagogy and content	TPCK 1. Demonstrating abilities / the ways teachers identify the necessity of using technology in the selected topic and based on students' needs 2. Demonstrating abilities / the ways teachers use suitable technology to teach the content that is difficult to present by traditional means and teach the content with appropriate methods 3. TPCK an emergent and 'unique' form of knowledge moving beyond TCK and TPK

Adapted: Benson and Ward (2013); Lee and Kim (2014); Ouyang, (2015)

Appendix 5.3: Deductive and Inductive Codes - AT, ICT-CFT, TPACK

A coding framework for data analysis: Activity System, ICT-CFT, TPACK Codes & Descriptors

Activity System (AS) Codes: *Object, Tools, Rules, DOL, Community*	**ICT-CFT** Codes: *Understanding ICT in Education, ICT, Curriculum and Assessment, Pedagogy, Organization & Administration, Pedagogy and Teacher Professional Learning,*	**TPACK** Codes: *TK, TCK, TPK, TPACK*
Object of ICT integration Problem space that head teacher and teacher subjects are working on and the goals they are seeking through use of technology	**Understanding ICT in Education** Rationale, goals & vision for how and why ICTs should be used in schools	**ICT - TK** Teachers knowledge and practical experiences of teaching and learning and applying ICT tools in classroom practice
Tools & Resources Mediating tools that allow head teacher and teacher subjects to pursue objects.	**ICT** Computer hardware, software, data and networks, information resources, technical support	**Technology Knowledge – TK** Tapping technology knowledge to use different technology tools and resources and to create different artefacts – for use of in the classroom
Rules & Regulations Conventions/ expectations that constrain/ influence activities in the classroom, school or organization learning system – explicit & implicit	**Curriculum & Assessment** • Understanding of key concepts and their application to solve routing and complex problems; • STEM & 21st century skills – interpreting, analysing, manipulating information & data for sustainable development in a digital society; • alternative and continuous assessment embedded in practice;	**Technology Content Knowledge - TCK** Understanding the relationship between technology and content within the classroom and how each influences and limits the other
Division of Labour Role of teacher & learner that they assume when carrying out the activity	**Organizational & Administration** Conceptualization of learning spaces, learning opportunities with flexible timing and pacing, timetables and organization of learning **Pedagogy** Pedagogies that emphasize teaching and learning with and through use of technology	**Technology Pedagogy Knowledge - TPK** Understanding the relationship between technology and teaching and how teaching can be affected by the technological choices made
Community Group with shared interest in the outcomes	**Teacher Professional Learning** New teacher roles, new pedagogies and new approaches to teacher education for the use of technology to support student learning	**Teacher Technology Pedagogy and Content Knowledge- ICT-TPACK** The interconnection and intersection of content, pedagogy and technology. A way of thinking about teacher 'unique' use of TPACK multiple knowledge domains
Adapted: Yamagata-Lynch 2008, Engeström *et al.,* 2013; Terpstra, 2016	Adapted: UNESCO 2008, 2011; Butler *et al*., 2013	Adapted: Harris, 2008, Niess, 2008; Angeli and Valanides (2009); Ouyang (2015)

Appendix 5.4: Examples of Qualitative Thematic Analysis

Worked example: Analysis of Interview Data – AS & ICT-CFT Emerging Themes

- **Column 1:** Text transcript segments of data highlighted for *Activity System Division of Labour - Roles & Responsibility* codes, codes contain annotations of potential patterns (themes) emerging
- **Column 2**: AS candidate themes emerging in head teacher discourse on aspects of changes in teachers and student roles planning, e-learning culture and new pedagogy (semantic and latent themes)
- **Column 3:** ICT-CFT candidate themes emerging in head teacher discourse linked to a systems perspectives of school organization and management, ICT use to support pedagogy - opportunities and tensions (latent themes)

AS Interview Data	Deductive analysis	Inductive analysis
School B – Head Teacher (SB-HT) Transcript Extract Roles & Responsibilities: Codes and notes	**AS – R&R Themes and sub-themes** Thematic frequencies derived from all head teacher interview data sets (SA-HT; SB-HT; SC-HT; SD-HT)	**ICT-CFT theme and sub-themes**
RQ: What specific responsibilities do the actors in your institution assume to achieve the school goals for ICT integration? **Probes:** Are your teachers comfortable with using computers? How many of your teachers use/do not use the computers/ laptops / projectors on a regular basis? • One of the greatest challenges that restricts the use of computer in the school – there is not enough rooms are free so that you can take your students –and take them there for that .STUDENT ROLES - E-LEARNING CULTURE – LIMITED ACCESS • Maybe I could say that the teachers use of computer a lot – even for their work – for preparation of lessons – for Masters programmes for learning process and use it almost weekly – about 50% of the teachers use the computers in this way –TEACHER ROLES - E-LEARNING CULTURE - EVIDENCE OF USE • Computer use is a new phenomenon in Kenya – this is not something we are used to. We have been learning for the last year 6 years –E-LEARNING CULTURE – NEW PHENOMONEN • We have the CEMASTEA – they introduced the use of ICT targeting the science NEW PEDAGOGY – USE OF ICT TO SUPPORT SCIENCE & MATHEMATICS PEDAGOGY • The humanities and language teachers felt they were discriminated against – PEDAGOGY - GAPS - OTHER SUBJECT DISCRIMINATION • There has been resistance to change – the chalk and talk – that has been the order in Kenya – the teachers in Kenya of my age 45+ and above – PEDAGOGY - DIDACTIC – RESISTANCE TO CHANGE–	**Roles and Responsibilities** **Planning** • Nothing formalized for roles and responsibilities – need to put in writing designated roles – (SA-HT) **Changing School Culture – Spaces for E-Learning** • Computer new phenomenon in schools in Kenya – (SB-HT) • Limited access to e-learning facilitates for teachers and students greatest challenge – (SA-HT; SB-HT; SC-HT) • Some teachers are comfortable with technology – due to training initiatives taken by school & national level (SA–HT; SC-HT) • Between 50% (SB-HT), 70% (SA-HT) and 80% (SD-HT) of teachers use computers regularly (on a weekly basis) in their subject teaching • Workload of 25 lesson per week – some with 30 – others with 18 (SC-HT) • Technicians maintain computer labs – (SA-HT) **Changing Pedagogy – Uptake & Resistance** • National agencies of CEMESTEA introduced ICT course for Science and Mathematics teaching – (SB-HT) • Student and school expectation of teachers to use technology; compelling teachers to get used to the tools for instruction – (SA-HT; SC-HT; SD-HT) • SIPSE STEM teachers influence ICT infusion in school activities – (SA-HT) • Teacher of other subjects discriminated against (SB-HT) • Focus of teacher ICT use for professional purposes – planning and preparation of lessons, register of examination results – (SB-HT; SC-HT; SD-HT) • Resistance to change; chalk and talk culture; older 45+ teachers (SB-HT)	**Organization & Administration** **Opportunities:** • Computer usage an emerging phenomenon in Kenya schools over the past decade • Graduated teacher sense of ICT efficacy **Tensions:** • enabling conditions of access limited • Historical association of technology use as specialist subject situated in computer lab / • Overloaded curriculum • Lack of formalized roles and responsibilities **Pedagogy** **Opportunities:** • Models of CPD emerging for use of ICT in STEM subject teaching and learning • Culture of expectation for technology use to support new instructional practices • STEM Teacher Influence other subject teachers on new technology use **Tensions:** • Lack of pedagogical integration of ICT across all subject teaching • Teacher use of technology on periphery of classroom practice – concentration on lesson planning and exam activities • Epistemological limitations – chalk and talk model spill over into computer usage model of knowledge transfer

Source: Head Teacher AS Interviews, September 2014

Worked example: Analysis of Focus Group Discussion Data – TPACK & ICT-CFT Emerging Themes

- **Column 1:** Text transcript segments of data highlighted for TCK codes, codes contain annotations of potential patterns (themes) emerging
- **Column 2:** TPACK candidate themes emerging in teacher discourse on aspects of what TCK looks like (semantic themes) and teacher design ideas on affordances supporting/ constraining practice (latent themes)
- **Column 3:** ICT-CFT candidate themes emerging in teacher discourse on aspects of ICT affordances in school system practice - opportunities and tensions (latent themes)

TPACK Focus Group Data	**Deductive analysis**	**Inductive analysis**
School A (SA) Focus Group Transcript Technology Content Knowledge (TCK) - Codes and notes	**TCK - Themes and sub-themes** Thematic frequencies derived from SA data extract (SA-LT; SA–TO3)	**ICT-CFT-Themes and sub-themes**
Lesson teacher (LT) The technology that I applied was the PowerPoint using simulations and videos, and the students… appeared to … to understand what was happening… and they didn't analyse… they liked the technology because the different groups…. (inaudible) abstract – when you talk of the absorption of materials which have been filtered, sometimes they don't understand, but when they see it happening in the simulation, it becomes clearer to them… and they are able to understand better because of the technology…TCK – Simulation Content Representation & Understanding Teacher Observer 3 (TO3) Emm…. the teacher was asking, the ,,, the level of the questions were higher level, and the students were able to answer them, which meant they understood what, what the teacher was teaching, lemmm… I never did Biology myself, but I looked at the, I was able to learn some bit of expression together with the students and I enjoyed the lesson… and eh, the simulation of the kidney, I think that was an area where I found the students glued to the screen, their eyes were there, quite attentive, TCK – Simulation Content Representation & Understanding and eh, when there was the, the other teacher in (the video) was teaching instead of Teacher X, TCK – Technical Challenge – Adapting External Content the students were very attentive also, and later on when he asked them questions, they were able to answer, and also asking questions as they were going on… and eh… I think the lesson was quite ok, TCK – Effective Knowledge Transfer emmm, the technology he had some bit of a …. Problem in operating the technology, which is normal (small laugh) I would say, because at times you can prepare, but when you reach eh, the technology will fail you… but with Teacher X he was able to em, is it to troubleshoot, that is the technical language, to do it properly for the students, and the lesson went on well, until the end…TCK – Technical Challenge - Troubleshooting content data bank	**TCK – Software affordance for deeper understanding of 'hard to teach' concepts** • PowerPoint presentation affordance for embedding simulations (SA-LT, SA-TO3) • Deeper conceptual understanding - simulation visualization of 'nephron absorption' processes (SA-LT, SA-TO3) **TCK – software affordances for learner engagement** • Motivation and enjoyment of students (SA-LT, SA-TO3) • Local and global content perspectives via video teacher explanation (SA-TO3) • Technical challenges – adapting and presenting content for student learning needs (SA-TO3)	**Curriculum & Assessment Opportunities:** • **Simulation enhancement** in presentation – enabling teacher explanation of complex concepts - system functioning of nephron absorption processes • **Motivation** - use of images to enhance student understanding and meaningful engagement • **Added value of technology** to link theory with practice (illustrate nephron systems); abstract concepts to real world simulations **Tensions:** • **Knowledge transfer:** Simulation centred in teacher lead whole class instruction – f2f and virtual • **Assessment:** Under-exploration of simulation affordances for interactive student engagement in problem solving / for deeper knowledge sharing and assessment on systems analysis (what if/ prediction questions) • **Logistics:** challenges in locating and adapting content to learner needs and curriculum objectives

Source: Transcripts Focus Group Discussion, Science problem-based learning, School A, September 2014

Appendix 5.5: Codes – Teacher Design INTERACTIONS

A categorization matrix for data analysis

TPACK Categories Utterances	**Process Based CODES**	**Knowledge Based CODES**
Pedagogical Knowledge (PK)	Analysis – describe current practice Analysis – clarify current practice Analysis – justify current practice Analysis – justify new practice Analysis – predict outcome of new practice Analysis – confirm new practice Analysis – Identify problems with new practice Design – propose design strategy Design – conceptualize new practice Design – propose new practice Development – create new practice	PK New PK (Gap) New PK (Refine) New PK
Content Knowledge (CK)		CK New CK (Gap) New CK (Refine) New CK
Technological Knowledge (TK)		TK New TK (Gap) New TK (Refine) New TK
Pedagogical Content Knowledge (PCK)		PCK New PCK (Gap) New PCK (Refine) New PCK
Technological Pedagogical Knowledge (TPK)		TPK New TPK (Gap) New TPK (Refine) New TPK
Technological Content Knowledge (TCK)		TCK New TCK (Gap) New TCK (Refine) New TCK
Technological Pedagogical Content Knowledge (TPCK)		TPCK New TPCK (Gap) New TPCK (Refine) New TPCK

Adapted: Koh, Chai, Wong and Hong (2015)

Appendix 5.6: Codes – Lesson Artefacts

A TPACK Framework for Analysis and Mapping of Teacher Lesson Plan & Observation Note Data Sets

Angeli and Valanides (2009) **Content Representation**		Voogt and Pelgrum (2005) **Pedagogical Uses**	Harris, Mishra and Koehler (2006) **Activity Types**
ICT & Non ICT Representations • Pictures & symbols in texts • Digital images and text view association • Record & hear sounds	Tool Affordances • Visualization of the concepts • Textual & Pictorial representation • Auditory Representation	**Didactic Pedagogy** (industrial society) • **Active** – activities prescribed by teacher; whole class instruction; little variation in activities; pace determined by programme • **Creative** – reproductive learning; apply known solutions • **Integrative** – no link between theory & practice; separate subjects; discipline based; individual teachers • **Collaborative** – individual; homogenous groups; everyone for him/ herself • **Evaluative** – teacher directed; summative	Knowledge building • *build student content-related understanding of a given topic students through information-based processes* Convergent knowledge • *develop student skills to create, respond to, or complete structured representations of prior knowledge building*
• Hyperlinks	Multimodal representations: • Auditory • Textual • Visual • interactive	**Constructivist Pedagogy** (information society) • **Active** – activities determined by the learner; small groups; many different activities; pace determined by the learner • **Creative** – Productive learning; Find new solutions to problems • **Integrative** – theory and practice; relations between subjects; thematic; teams of teachers • **Collaborative** – working in teams; heterogeneous groups; supporting each other • **Evaluative** - student directed; diagnostic	Knowledge Expression • *build student deeper understanding of content-related concepts using various types of communication* Divergent knowledge • *help students to extend their content-related understanding via alternative forms of communication*

A TPACK Framework for Analysis of Teacher Observation Notes

	Problem-based Lessons			
Activity Types	Use of technology to support content (TCK)		Use of technology and pedagogical strategies (TPK)	
	What did you think worked well?	And less well?	What did you think worked well?	And less well?
Knowledge Building Activity Types				
Knowledge Expression Activity Types				

Adapted: Harris, Mishra and Koehler (2006); Angeli and Valanides (2009)

A Framework for Analysis of Teacher Observation Notes – Characteristics of Student Learning in Webquest Project Presentations

	Project-based Lessons				
Student Presentations	Group Organization	Group Content	Group Presentation	Group Research	Group Communication
Active					
Collaborative					
Creative					
Integrative					
Evaluative					

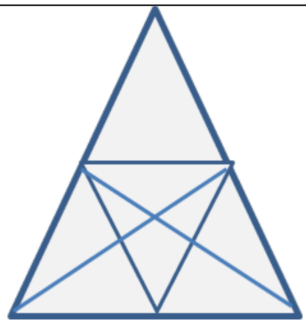
Adapted: Voogt and Pelgrum (2005); Dodge, B. and Pickett, N. (2007)

Appendix 5.7: Thematic Mapping

Theme Mapping: TPACKtivity of ICT-CFT-TPACK-in-practice

Codes AS, ICT-CFT, TPACK

- **AS:** Subject, Tools, Object, Rules, Community, Division of Labour, Outcome
- **ICT-CFT:** Understanding ICT in Education (policy), Curriculum & Assessment, Pedagogy, Organization and Administration, ICT, Teacher Professional Learning, Module of 21C Teacher Professional Learning
- **TPACK:** ICT-TK, TCK, TPK, TK, TPACK, ICT-TPACK

	Tools **ICT** **TK**		
Subjects **Teachers** **Head Teachers**		**Object** **Understanding ICT in Education** **ICT-TK**	**Outcome** **Module of 21C Teacher Professional Learning** **ICT-TPACK**
Rules **Curriculum & Assessment** **TCK**	**Community** **Teacher Design Teams STEM & Other Subjects** **Teacher Professional learning** **TPACK**	**Division of Labour** **Organization & Management; Pedagogy** **TPK**	

Cycles

- From *Technology Literacy* to *Knowledge Deepening*;
- Knowledge Deepening: From *Problem-based* to *project-based learning* lesson try-outs

Adapted Terpstra, M. (2015)

Appendix 5.8: Thematic Prevalence

Prevalence of AS Themes in Head Teacher and Teacher Interviews

Activity System Domains	Head Teacher Interviews Thematic Frequencies	Teacher Individual and Group Interviews/ Questionnaires Thematic Frequencies	Prevalence of themes (%)
Object of Learning	9	9	18/265 (7%)
Object of ICT use in T&L	34	16	50/265 (19%)
Tools	33	30	65/265 (25%)
Division of labour – teacher and learner	20	31	51/265 (19%)
Community	8	18	26/265 (10%)
Rules and regulations	15	40	55/265 (20%)

Prevalence of TPACK Themes in Problem and Project-based Lessons

TPACK Constructs	Problem-based Lesson Thematic Frequencies	Project-based Lesson Thematic Frequencies	Prevalence of themes (%)
TK	18	8	26/ 269 (10%)
TCK	60	4	64/ 269 (24%)
PCK	26	23	49/ 269 (18%)
TPK	76	24	100/ 269 (37%)
TPCK	26	4	30/ 269 (11%)

Appendix 6: Selection of Transcripts and Artefacts

Appendix 6.1: Transcript – Head Teacher Interview

Skype Interview - Activity System Interview Schedule
School: A
Date: 30/09/2014
Researcher; School Head

1. Background school contexts

Researcher: Can you tell me a little bit about the school, about School B, how many students, boys, girls, how many teachers, departments, and so on. Just some background information.

Head Teacher: School A is a boy's boarding school with 977 students. We have a teaching stuff of over 60 and 32 members of management team staff. In the implementation of the curriculum, the school programmes are divided into departments. We have the languages, we have mathematics, we have the sciences, we have what you call humanities as well, we have subjects like history, geography and eh government and CRE studies, we also have Islamic studies and then we have department that deals with what we call commercial (inaudible] those are and some of the subjects that fall under foreign subjects like French, German, we also have music falling under that department. We also have what we call applied subjects that would be woodwork, they are technical in nature - there are many… there are 10 subjects, metalwork and all of that into what you call, em, applied. Now that is on the curriculum implementation.

On em the administration side, the students are either basically in dormitories or hostels that [Inaudible] and they are managed by a dean and they are also in class and they are managed by a teacher in charge of academic. So that is basically how I can summarize the structure of the school. One other thing…. I was saying em, that the school is divided into those areas. Now we have 2 deputies and one principal and of course the schools is managed by a board of management and we are supported by the ministry. So I think that is what I can say about the em, the background of the school. I don't know whether I have captured all that you needed.

2. Curriculum objectives for teaching and learning and ICT integration

Researcher: Thank you. Does the school have a particular focus in its curriculum? You have identified that it's academic and technical, is there any other focus?

Head Teacher: When it comes to curriculum implementation, you have the traditional ah way of delivery – ah that is when is [inaudible], we call it chalk and talk. But we are trying to move em… or shift our way of delivery towards the ICT… so our focus now is towards ICT and how we can use it to, to, to deliver ah the curriculum and also in the area of administration of the school, we are using ICT, so the emphasis now, other than just the traditional way of teaching we are now in the process of shifting towards eh ICT… technology.

Researcher: Thank you very much. I think you may have answered my next question, are there any particular issues faced by the school, you have already talked about the issue of chalk and talk and the shift towards ICT integration. Is there any other issue that you wanted to bring up?

Head Teacher: Maybe if I brought up the next issue, it would be the challenges in the implementation of the ICT. Basically the challenge in shifting is the fact that we have a large number of teaching stuff who will fail to embrace the changes, the new ways of doing things [Inaudible] and eh that is borne out of the fact that eh human beings are naturally slower at adapting to changes or appreciating changes [inaudible]. So I think that is challenge that we are facing. Of course another is the capacity of the same teachers. They may be willing but their capacity to deliver the curriculum in the direction may be wanting in IT

Researcher: The issue you mention on teacher capacity to deliver the curriculum for ICT integration. What is the reason?

Head Teacher: We have teachers who have been in the profession for the last maybe 20 to 25 years and therefore at that time in their colleges – the computers were not there. Secondly we also have teachers [Inaudible] but in the university there is no training for teachers on how to use ICT em… to deliver their curriculum.. because most of the lecturers at the universities - you can imagine ... those who are doing the teacher training… at the moment they may not be versed with the technology… so I would say that the problems stems from the university.

Secondly, it's also a societal issue – firstly you can imagine when you embrace technology you may lose your job because eh computers will take over what you are doing… and em the authority of might have been someone invited to the teacher is going to be [Inaudible] because we are going to have computers, we need to appreciate that computers are just guide like machines and they only help us do work even faster and [Inaudible]… So I think that the challenge is stemming from the training from the university level and even post qualification training … because at the moment we do not have programs that are geared capacity building the teacher to use technology in their teaching – other than what they were trained in college

3. ICT policy & vision

Researcher: Does the school have a policy or a vision or a plan for the ICT in teaching and learning - and if yes what is it?

Head Teacher: Em, thank you, em the question that you asked is what personal question about that the policy of school [Inaudible] we do not have em a policy in writing… but we have intentions on what we would like to do, and therefore I can almost say that would be translated into a policy position for the school.

We do have a direction that we would like to take as a school - one we would like to look at in the next 5 – within 5 and 7 years, we would like to see whether the students are able to have their own eh gadgets, and the teacher em delivers the content not just in class, but even after class, the students are to have (access) they are able to engage themselves… outside the class or outside the school time.

So we look forward as a school in moving in the direction and what we have done at the moment is em… we have set aside in our budget, we have an allocation of about 3 million per year[36], that allows a school to build on em, on the ICT equipment, to buy computers and other accessories where we will be delivering. What I mean by this is that em… we plan and we do… every year we buy twenty computers and em 3 laptops and em 3 projectors. So we are looking like at the position that in the next 5 years I will have enough of those laptops and em projectors that will allow mounting them in the classroom – other that what is happening now, where the teachers are going to class with the projector. So we are going out of our way not waiting for the government to give us anything but eh we have done a deliberate budgetary allocation as a school where we are now buying the equipment

Secondly the other that we have done deliberately is to install fibre, em optic fibre within the school that allows us to have a more reliable and faster internet connection. This is for both the teachers and the students… we have a room where the students can go to do their own cassette with ICT [Inaudible] and we have about 40 computers in that room and all the computers are connected to the internet. Ah, besides we also have a separate [inaudible] room for students who have to take computer (as a specialist subject) … so basically we want to use computer as a tool in our curriculum implementation and capacity building for the students.

Second, toward the end of that question, I have a personal vision which I have shared with their parents at some point, but of course we normally have a constraint … but the parents can imagine the students having their own tablets within the school, and of course there are going to be challenges about the safety [of the same], but the intention is let's have every child… em, for every student a tablet, where they will have all the resources that they need formally.

What is happening currently, if you will allow me, em the Government gives some money – about 3600 shilling per child[37] towards tuition, the purchase of tuition materials. This 3,600 em, over a period of 4 years, amounts around 15,000, and if the same money were to be translated into a reasonable tablet for the child within two years, the same amount of money could be used for buying a tablet for the student ….and all the content that the student needs for the 4 years will be here. I have been talking all over – so I hope I was catching some issues that you wanted – thank you

Researcher: Are your vision and objectives for ICT directly or indirectly link to the national vision for ICT integration – and if so how are they related? Have the objectives changed since the SIPSE teacher development program was introduce in the school and how they have changed?

Head Teacher: Let me answer the last question first on whether my vision has changed after the teachers just went through SIPSE, I would say yes, because I now realize that em it's not just about the laptops, it's not just about the

[36] Kenya Shillings 3 Million = Euro 27,000
[37] Kenya Shillings 3,600 = Euro 32

devices that the teachers can use , even their own portable devices can be used in class in subjects for curriculum delivery, so when I say that it has changed my mind [Inaudible] to allow me to a accommodate other devices.

Em, about my vision, whether my objectives been made and whether I aligned the overall goal with the ministry of education, because currently what the Ministry of Education is doing, in fact about an hour ago, I just talked with the Director of Secondary and Tertiary education, and he confirmed to me that the ministry is passing about a million shillings to schools to buy computers and laptops for their schools – so what I am saying is, what the Government is doing is what I am doing

So what the ministry are doing, we are doing, so by inference our objectives are the same. My objectives and the Ministry objectives for the curriculum course of delivery are the same.

4. Subjects

Researcher: Thank you. Who is involved in ICT in the school?

Head Teacher: I think, em, what the STEM teachers are doing is to capacitate the other teachers, what they are doing, is em, they are trainers of the other teachers and therefore when it comes to the use of ICT in the school, I would say that first every teacher is supposed to use the ICT, in fact eh, if I put it this way, there is a specific period within the week, where as a subject teacher, you are supposed to take the students to the ICT lab for a normal lesson, it could be teaching biology, and eh, instead of teaching the biology in the classroom, or in the lab or the science lab, I take the students to the ICT room, where they will now access the net, access more materials with the guidance of the teacher. So I would say that everybody within the school is using ICT and their curriculum delivery or even in the administration.

Now in administrative duties this what we do as a staff, setting of exams em, is done ah, using the computers. The teachers will not bring the paper, unless on email, where the head of the department is going to verify slandered and they do the moderation and sent back to the teacher for final corrections and submissions for printing.

The same thing with the entry of exams in the computer, we analyse all our examinations using the computer, and even communication with the parents, that's what we do… when we have to send a message to the parents … we use the internet messaging to do that …as within my office… we have so many meetings with the teachers and my directors….so that (they prepare) before coming for the meeting… so that during the meeting I am able to access the information and said information from my deputies on their portable devices… so in this way we are able to challenge every person to make use of the computers. Because basically what will happen is, if we do not create objectives for people struggle with and use computers, they will fall back and relapse into what they are doing.. using written, using hard copies that way… . so I think the administration I don't know anything specially the another may be admission purpose.

Researcher: Thank you. It seems to be that your vision is actually permeating all the practice in the school. Whose role dominates the objectives for ICT use?

Head Teachers: I think other than the STEM teachers in the use of ICT, we don't have any other person that is dominating the use of ICT at this point.

5. Tools – ICT and Non-ICT Resources

Researcher: Thank you. The next question is about what recourses you have in the school - ICT and non ICT that are available for programs like the SIPSE program or other programmes. What recourses do you have? What resources do you see that you need?

Head Teacher: The resources in terms of general curriculum delivery or the ICT. Let me start with the non-ICT recourses. I believe you talk about the classroom facilities, the labs and all that? Ok – let me go ahead - we have 20 classrooms, we have 5 science labs, we have one ICT room, one computer lab. We have workshops for subjects that are technical in nature. I think that's what we have about and then of course we have the library, where we have many books hard copies stored.

Now when it comes to ICT- em, I will be thinking aloud as I answer your question, I hope you don't mind that. Of course we have close to a hundred computers – in the school we have about a hundred computers, both for, for use by the students, by the teachers and for the administration purposes, because em, as I mentioned to you, the school embarked on a programme for the last eh three or four years, in purchasing computers every year – every year we purchased about twenty computers. So we have put 100 computers in the school. We have seven laptops and projectors for use by the teachers - and of course we have internet 6mbps, the internet speed. As I mentioned to you earlier, that's on fibre, so I think I have answered the question.

6. Roles & Responsibilities

Researcher: I think you have answered some of the remaining questions already. Are there different roles for those who are involved like for example you as principal, your heads of department, the STEM teachers. Are their different roles in terms of realizing your vision?

Head Teacher: Ok, the ones that we have clearly right now, we have for the STEM teachers that is clearly defined. We have formed an ICT committee in the school. What they do is, they do assessment of ICT infrastructure and needs… so we have a committee that is chaired by a head in charge of computers, … we have 2 technicians who man the 2 computer lab. We rely on them to lead in the school. The rest I think you are now telling us to put our things in writing… everybody knows what they are supposed to be doing… so for posterity we will write roles for every person who are in charge or who will have something to do with ICT.

Researcher: Thank you very much. You were talking earlier about how building teacher capacity in the school or computer use to deliver the curriculum. How many of your teachers would you say use computers, laptops whether their own laptops or the computer lab and projector on a regular basis? Regular being once a week or so?

Head Teacher: Eh, seventy percent, seven… seventy percent. Seven zero.

7. Community

Researcher: Does the school work with other schools and institutions to meet the goals for ICT integration? What is the situation of networking with other schools or partners?

Head Teacher: I think all schools work in isolation …because the problems that we have here, you may not have in the neighbouring school… and basically it's because em, you know we do not have a national policy of integration of ICT in our schools. It comes once in a while just as a circular, but there is no policy on that … so because there is no policy, schools will always allow the leadership or their principal to drive the ICT policy agenda within the school. So it is difficult to say that we are working together. What we have here is developed from what the school has and as I said, it is out of the sheer eh hard work, or whatever, of the teachers.

8. Beliefs about teaching and learning with ICT

Researcher: You were talking earlier about chalk and talk and the pedagogical shift. I have one question about your vision for teaching and learning with ICT. If you went into a classroom today of a good SIPSE teacher who is using ICT in their practice, what would you expect to see?

Head Teacher: What I would expect to see personally, it's stemming out of my vision, I would expect to see the teacher avoiding the use of chalk [inaudible], and the teacher gives homework through the portable device, the notebook should only be used for a reference of what the teacher is sharing, but then most of the work should be given by reference books, but that is what I expect. It will not be today, it will not be tomorrow, it will not be the other year, but somehow that is what I expect, that em, within a short time, we will have what you call a 'chalk less school'. We will use very little money to procure stationary, so that is my vision and I em expect the STEM teachers to take the lead in the whole thing - that is what I expect. Thanks.

Researcher: What do you see has been the impact of SIPSE on ICT use in the school? What was the impact? Who was impacted? How did the project and the school contribute to the impact?

Head Teacher: I think the greatest impact was the minds of the teachers was opened. We appreciate the use of the technology in class. For the first time we saw teachers who say that their mobile phones can be used to teach. So the person that was impacted the most in my view were the teachers.

Now on the question how? I think after the training em, the teachers, the STEM teachers took it upon themselves, when they are sitting in the department, to talk about the SIPSE program and the tools are able to use. And the other question is who was the most. I think I will talk about the leader Mr. X (School based lead coordinator), the one who was leading and who is still leading inspiration for the teachers in the use of technology.

So I think that what is my answer for that. And of course I am not want to the fact that the students are more… they enjoy their lessons for those teachers who are going to use the programme, the SIPSE programme, the students are enjoying their lessons. You see the students moving very fast where these lessons are being delivered. Then the other one is emmm, the use of… technology. I think for the first time you have teachers who come to sign for the use of the projector and the laptops and like where the laptop and the projector was used for meetings only, but not usually [that] you have teachers coming to sign for those devices to go and use them in class. So it might be this [Inaudible] we may not have [Inaudible] but there is a shift in how we do things that is a result of SIPSE programme. Thank you.

Appendix 6.2: Transcript – Teacher Focus Group Discussion

Post Problem-Based Lesson - Focus Group Discussion

School: B
Date: 24/09/2014

Researcher:
Lesson Teacher: Biology Teacher

Teacher Observers:
Teacher Observer 1 – English Teacher
Teacher Observer 2 – Mathematics Teacher
Teacher Observer 3 – ICT Teacher
Teacher Observer 4 – Physics Teacher
Teacher Observer 5 – Chemistry Teacher

TPACK Question Domains	**Transcripts** Teacher 'talk-back' and 'design thinking' conversation following a live lesson observation: What worked well? What worked less well? What can be improved?
On Content, Technology and Pedagogy	**Researcher** We start with you Teacher X (lesson teacher). You have filled in your lesson self-review on content, technology and pedagogy integration in the lesson. What do you think worked well? How can you tell?
	Lesson teacher - Biology They were fair…mmm… ok the PowerPoint presentation was ok… mmm it was in line with what we do with the girls in class, the only challenge was ah… because of the internet issue, getting the appropriate clips, was a bit of a challenge, so I don't think I, I got the best of the clips to use, especially when I was doing the video presentation..
	Researcher Appropriate in what way? Can you explain further…?
	Lesson teacher - Biology Mmm ok – photosynthesis is a process that goes on in Plans (eh hem)… and actually you can get more materials that show the real process and how it occurs…but because of limitation of time and getting access to the internet…I was not able to get a real appropriate one
	Researcher When you say show the real process, what were you looking for?
	Lesson teacher - Biology Like you see the…ok what we had was more of a presentation from another teacher (eh hem), but we could have had a better clip where we show the light being trapped, combined with … I mean em…spilt the water so you form the different molecules at every stage…
	Teacher observer 1 - English So you mean the more detailed one…the more detailed…
	Lesson teacher - Biology Ok the ones which were available only – most of them had too many details… so I couldn't get an appropriate one for this level of students, especially one that explains the process, the real live process, yeah and I think if I had more time I would have got that...
	Researcher So there were time issues (yeah – lesson teacher) and also there was a level issue, of finding materials appropriate for students...
	Lesson teacher - Biology Yeah, because normally what they have only, they give a little bit more details than what we cover at the level so…mmm I think if I got an appropriate one that could have worked better…
	Researcher So this is an issue in teaching content with technology, is that what you are saying, finding materials appropriate for the different levels of your students?

TPACK Question Domains	Transcripts Teacher 'talk-back' and 'design thinking' conversation following a live lesson observation: What worked well? What worked less well? What can be improved?
	Lesson teacher - Biology Yeah because sometimes online maybe the details are too much or you are not able to get an exact one that fits that particular lesson so – yeah – I think that was the biggest challenge but the rest… maybe they (gesturing to other teachers) can talk about what they saw in the lesson…
On Technology Content Knowledge (TCK)	**Researcher** Thank you… so colleagues what were your observations – what did you see and what did you think about technology use to support lesson content…
	Teacher observer 4 - Physics What she is trying to say is there should have been a clip showing the real photosynthesis process in the leaves (yeah – lesson teacher), in the leaves (yeah, yeah – lesson teacher), the actual process, how it happens, like a picture, something pictorial…,
	Lesson teacher - Biology Yeah, yeah, pictorial could have done better…
	Teachers observer 2 - Mathematics Now my question is… is the problem lack of that material or time (time – other teacher observer)… so the baseline is time…
	Lesson teacher - Biology Time was an issue and then most of the pictorial clips online, they have more details than at this level for
	Teacher observer 2 - Mathematics So the issue is time… because if you had more time (you could organize --- teacher observer 5), you could organize isn't it… so the issues is (yeah, yeah) so the issue is time… then ah from what was being projected, we could only read the main… the main heading…
	Lesson teacher - Biology For the PowerPoint or the video clip?
	Teacher observer 2 - Mathematics For the power point (ok – lesson teacher) we could not read the small writings (you at the back – lesson teacher) eh… so unless now you explain it, we were only seeing the main ones (charts) the chart , we were seeing the boxes containing some writing, but we could not read them (ok – lesson teacher) so set up, the setting up (I've already see the words in the slides, make them bigger), you expand the area, the projection, and then it is moved up, a bit up (inaudible – lesson teacher) these one, the ones that were here were blocking, the writings ones that were on the lower side (the set up – lesson teacher), it should be up and then wide…
	Teacher observer 1 - English The concept map (the chart – lesson teacher) that chart yeah … between those various area there so that's easier for the students to understand the process…
	Teacher observer 2 - Mathematics But that's something that can be done easily (easily – lesson teacher)… yes easily…
	Researcher So we are already giving feedback on technology support for instructional strategies [concept mapping]… and eh from what I am interpreting – you were looking at the content, you were looking at the technology to support the content, have you anything further to add on the technology use to support content concepts in the class? …
	Teacher observer 1 - Biology I observed that the content was very good, em since there is em the newness, the newness, the way the content is being imparted to the students, so they are able see the various, the various em, the various em parts, this is a process, this is a process,,, because it is (inaudible) so em em, I am not very good at bio, but I thought that it was a lesson that em …got to the students, got to the students, I think they understood the process better… than the actual work that they are used to here, talking, just talking and writing a few things on the blackboard – so there was a good link between those two, we don't get claps every other time after a lesson do we (laughter), we don't get claps, so when the students clap you're feeling you have taught a successful lesson, so the content was very good and it was internalized by the learners…
	Researcher

TPACK Question Domains	Transcripts Teacher 'talk-back' and 'design thinking' conversation following a live lesson observation: What worked well? What worked less well? What can be improved?
	Very interesting observations on student reaction to blackboard and technology representation of content … Eh anyone else on content… What other notes did you have on content and technology from your observation sheets?
On Technology Content Knowledge (TCK)	**Teacher observer 5 - Chemistry** I would say there… of the students… I think they had some prior knowledge, I think they connected well with what the teacher was presenting, so there was flow, that's why there was so much interaction, when the teacher asked questions, they were able to answer,,, even personally on my side, I was learning a lot about it, at some point I thought I could teach Biology (laughter) yes, I found myself answering questions faster than the students and I like wait, what's happening here…
	Researcher We are now looking at two things in the observation in terms of what you see and what you think, what you think in terms of what worked – there's an awful lot that's working, but what could work better, you've already talked about aspects that worked less well (Teacher Observer 2) in terms of the content (visibility)
	Teacher observer 2 - Mathematics I think the content was the ideal one, it was very ok, very well presented, and it was picked well by the learners, emm, you could see, you could see even from the learner that ah, they were moving with the teacher step by step, step by step and the teacher was explaining, so on the issue of the content, that one was very ok, you know…
	Researcher Now are there any other aspects about the content?
	Teacher observer 3 - ICT Yeah I saw students asking questions at the end of the lesson so it show that the students were getting the concepts and contents of the lesson because the teacher's asked the questions and they were able to respond and at the end of the lesson the students asked the teacher some questions, so they internalized the content…
ON Technology Pedagogy Knowledge (TPK)	**Researcher** And I think you are bringing in aspects of assessment, you are observing the students internalizing concepts through their capability to ask questions… so now we are touching on pedagogy and we are looking at technology to support the pedagogy, Teacher Observer 4 do you have anything to say on this aspect?
	Teacher observer 4 - Physics Not really, the students were eager to learn and they seem to have gotten the concepts…
	Researcher The students seemed to have gotten the concept… would there have been a way to check that the students internalized those concepts based on technology tools like concept mapping introduced in the modules?
	Teacher observer 4 - Physics Yeah I think em… if there was time,,, there would have been a way of summarizing the lesson using concept mapping.. it would have come out very well for the students being able to relate the photosynthesis process itself…
	Teacher observer 5 - Chemistry They had been given that [concept mapping] as an assignment to summarize the process of photosynthesis on their own - other than the one that the teacher used here [in the lesson]…
	Teacher observer 1 - English As an evaluation…
	Teacher observer 4 - Physics Provoking their thoughts…
	Teacher observer 5 - Chemistry And they can also recall concepts that… that they were getting lost… through the concept map…
	Teacher observer 2 - Mathematics And also creating inter-links between… between various concepts…
	Researcher How can it be done? You mentioned as homework it can be done individually, in the class can it be done?

TPACK Question Domains	**Transcripts** Teacher 'talk-back' and 'design thinking' conversation following a live lesson observation: What worked well? What worked less well? What can be improved?
On Technology Pedagogy Knowledge (TPK)	**Teacher observers 2 and 3 (Mathematics & ICT)** Done in a group… as group work…
	Researcher [To the Lesson Teacher] You mentioned you had a concept map on your last slide, but there was no time, is it that there is no time for this kind of group work – or what do you think?
	Lesson teacher - Biology Actually I've been thinking about it… they'd work better if they were able to work in groups, to come up with the… the concept map…as a summary at the end of the lesson… much as they were given an assignment, I believe if they were able to do it during the lesson, it could have made more, it could have em… it could have been stronger for them… they could have understood it better, if they were able to discuss in groups, they could have come up with a concept map for the whole process…
	Researcher You say the end of the lesson – is there anywhere else you could bring it in the lesson?
	Lesson teacher - Biology Yeah, by the end of the light reaction, you could have had a concept map, for that part, and then (they continue Teacher Observer 5) and then at the end of dark reaction the same, and then combine them…
	Researcher We are still on your observations about technology to support pedagogy, anything else in terms of what you saw and what you thought worked well, could be improved…
	Teacher observer 2 - Mathematics Now em, the clips… on pedagogy the clips worked well, the PowerPoint presentation, the teacher's explanation, all that worked very well, eh, to bring out the… the matter of the topic, now I only have an issue on em, on it… because the students seemed to have a prior knowledge of some of the issues being discussed and they're bringing it into this area, now em, there's a slight chance, there's a slight chance, emmm, of some students, being left behind. The reason is, the question, the questioning-answering technique ah being applied, ah if the teacher asks a question and then a mob of the students answers, then it carries the whole class isn't it… so in a way some of the students might not have understood the concept, but because the majority have answered correctly, then some of the students might be left behind, ahhh, not knowing the… so that's the only area, if it's possible to break it down so that… you are able to get to be specific, isn't it, so that we can know if the whole class, or the majority of the students, do we have some students who are being left behind, that was my only area on methodology…
	Researcher A critical point on technology perhaps leaving students behind, (to lesson teacher), did you feel that any of your students were being left behind, did you feel that they were internalizing, and how did you know whether they were or were not?
	Lesson teacher - Biology There were some questions I asked them, and I noted there were some concepts we have done before, and some of them seemed not to be sure, so… and yet in some areas they were able to answer as a chorus… and you know that way you are not able to pick out who still has a challenge, and in which area…so… so I feel if ah… if there was a way to make them work in smaller groups maybe that could work better…
	Lesson observer 1 - English I felt em the questioning was good, if only em we could introduce some more em open questions, the questions asked were very direct and closed, they did not offer opportunity for us to expound on the same, I felt em, the video moved too fast, too fast, for the students to move with it, to move with it, it was helped by the fact that they had prior, prior, they seemed to have prior information on the same, so this is something that they are able to follow … I thought it was going a little bit fast, a little bit fast, so you have slow students will not catch up, they'd still be a little bit behind, yes, but of course it was a good lesson… don't be discouraged (no … those are facts – lesson teacher) yeah… (yeah, yeah – lesson teacher) yes…
	Researcher This is a good discussion – because the idea is to use this tool (peer-to-peer observation) to stand back and look at our lessons from our own perspective and the perspective of others… Anything further to add on technology and pedagogy?
	Teacher observer 4 - Physics

TPACK Question Domains	**Transcripts** Teacher ‘talk-back’ and ‘design thinking’ conversation following a live lesson observation: What worked well? What worked less well? What can be improved?
	Yeah maybe still on the questioning, I think that she would have had more control over them, such that she can have an opportunity even to ask those who are not ready to answer, to be able to make them more (inaudible), because the way they were answering questions, you ask a question and they all answer, there was an element maybe some would have felt intimidated,
On traditional and new TPK	**Teacher observer 3 - ICT** I saw students writing notes, so that one I thought it worked well, so as the teacher was teaching and they were observing the slides, they were managing to write some notes,
	Teacher observer 5 - Chemistry Some of them were not writing notes so I didn’t understand whether that is through the whole thing, they were interested in the watching, but they were not writing anything… so I did not know how to… I don’t know where to put them… as others were writing, others were just watching… so I don’t know whether those are the fast learners…?
	Researcher So you have a contrast here, some who are writing away, others not writing, where are they?
	Teacher observer 5 - Chemistry But they were very active, the ones who were not writing were the ones who were answering questions again… (laughter)
	Lesson teacher - Biology And I think if we use technology more frequently, it will em… make them get used to the idea, so that they don’t ah… I mean… the aspect of… I don’t know how to put it…
	Teacher observer 5 - Chemistry Writing it down, sit down and cram it… you know…
	Teacher observer 1 - English Em, em… the issue is getting rid of the excitement… that what the [Lesson Teacher] is talking about… (oh yeah so that they get into the idea – Lesson Teacher)… (that they get used to the idea… Teacher Observer 2), to the ideas that it is nothing new
	Lesson teacher So that so that they are able to take the concepts down and all that (em hem… Teacher Observer 1) (right… – Teacher Observer 5) … so that it becomes normal for them…
	Teacher observer 2 - Mathematics Remember writing is another tool that is used by some students to internalize information… (to internalize emmm… Teacher Observer 5)…so the taking of notes, the technology must not replace (the pen – Teacher Observer 5; em hem - Teacher Observer 1) the notes that the student need to internalize, so they all must be writing (writing something – Teacher Observer 1), so that at this time… write that down… so that they have some notes to refer to (ok – Teacher Observer 5) … otherwise the excitement is important for the lesson, for them to be with you … they don’t lose off their review… so you give a time to maybe put that down, unless you have an opportunity to give them handouts which we may not have at this level (em, em – Teacher Observer 1), then they must be left with some time to write something down… maybe the teacher in her teaching should leave some point, ah… ‘could you note that down’… so that they have some notes, then they listen to you and then you tell them these you have with you, then you give them a point to write something..
	Teacher observer 1 - English And I think the teacher did quite a good job at that and she was pausing eh…the video clip (she was explaining – Teacher Observer 5), pausing, explaining and asking a question at that point before continuing to the next concept… that was very good…
	Teacher observer 4 - Physics I think it was good, because if our students are used to it, even writing the notes, they would have done everything, writing the notes and listening, but the fact that they are not used to it, some were there wondering do I write, do I not write, otherwise on the part of the teacher, it was good…
	Researcher I want to go back to an observation you made [Teacher Observer 1] on open questions… what is our reflection on that observation [Lesson Teacher]… what do you think of the type of questions you asked?
	Lesson teacher - Biology Most of them were closed, because ok… this is a process that is definite… and the activities that take place during the process are almost defined… I tried to think of open questions, it was a bit difficult… I

TPACK Question Domains	Transcripts Teacher 'talk-back' and 'design thinking' conversation following a live lesson observation: What worked well? What worked less well? What can be improved?
	could only remember one… so he is right, I didn't have a lot of open questions… so it was a bit, the questions were a bit… most of them were closed… because it was a process and they needed to remember the facts… and explain what leads to what… you know something like that…
On traditional and new TPK	**Researcher** Let's not be too hard on our use of closed questions - closed questions are important questions – they have a role in the lesson for recall, remembering and understanding … do any recall any open type questions that you used …
	Lesson teacher - Biology Maybe the one on 'what could happen if plants did not photosynthesize'… That is the only one I can remember…
	Researcher It is very hard to think at the time – in module 4 we introduced a questioning checklist (you mean the current module – Teacher Observer 1, em – Lesson teacher) (em, em… on the templates… the lesson plan templates – Lesson Teacher) you have questioning checklists, because it is exactly as teacher X [Lesson Teacher] said, it is very hard to think at the time, it is not an easy skill, most of us tend to ask remembering and understanding questions…
	Lesson teacher - Biology On the templates the lesson questions, there are examples of questions on the templates – comprehending…
On Technology, Pedagogy and Content Knowledge (TPACK)	**Researcher** [Lesson Teacher] my last question is TPACK, how do you think it fit together in your lesson – your technology, pedagogy and content – did they fit together the way you wanted – or what would you do differently next time?
	Lesson teacher - Biology Em… they tried to fit together… maybe next time… ah… I will change on em… I will improve on involving the students more…apart from questioning, I could use the students in smaller groups more… and then improve on the technology also… yeah, what I have already mentioned about getting more clips, which can be more appropriate, yeah I think that will do…
	Researcher Colleagues who were observing, the TPACK - how did you feel it came together, what worked , how it could work a little more…
	Teacher observer 2 - Mathematics I think everything fell into place, as she said, with with eh, with more planning, more prior planning, it can be made better and em, especially the issue of ah… ah… making the students sit in small groups em… 1) for accessibility, and then for control and then also for… for monitoring… so that you are able to see the relevant standard of the students… but it was a very good lesson
	Teacher observer 1 - English I agree with you [Teacher Observer 2] that it fitted very well, it fitted very well, because you consider there is use of all three, there is use of all three, there is technology, the teacher is teaching using this and that method, and then the content is internalized, you are able to access that, to assess that, because the students at the end answer your questions, the students enjoy themselves, the students clap at you, so (laughter) so (laughter) so in the next lesson, when they bring the flow chart, you will be able to confirm that your lesson was successful, and eh…so I think it was very well done, you mixed, you used all three very well, you mixed them very well, em, and ah, it was a success, a successful lesson yes…
	Researcher This is a good critical feedback on designing a lesson… any final observations….
	Teacher observer 5 – Chemistry The lesson was good… I don't have any problems with it… I think the teacher tried her best… to capture everything in the TPACK, but what we need to realize, these things do not all come out in one lesson, they cannot… you will capture some, others will not capture, again even the questions, there are topics that are closed, like in Chemistry, I think I would be so closed, because they are facts (chemistry is factual… Lesson Teacher), Biology is a bit open, but Chemistry is factual, so some of the questions, some subjects may not, even Mathematics. Chemistry (em – Teacher Observer 2), what questions will Teach Observer 2 (Mathematics Teacher) ask, (laughter)… I will expect… I will expect definite answers….(Teacher Observer 2 – definite answers) (laughter) so… ah, we need to take account of that, that we cannot capture everything 100% in the one particular lesson… because we have to be realistic…

TPACK Question Domains	**Transcripts** Teacher 'talk-back' and 'design thinking' conversation following a live lesson observation: What worked well? What worked less well? What can be improved?
On Pedagogy Content Knowledge (PCK)	**Researcher** I like your observations (laughter) I think you have given us a challenge… is it that some subjects are more closed than others? Is Chemistry Closed? Is Mathematics closed? John you are nodding away (Em – Teacher Observer 2)
	Teacher observer 2 – Mathematics When I ask for the value of x – (you want it… Teacher Observer 5; you want the value… Lesson teacher) there's only (yeah… Teacher Observer 5) there's only one value of it (yeah – Teacher Observer 5) and the other one you give me is wrong (yeah – Teacher Observer) – if it's not the correct one (yeah – Teacher Observer 5) so…
	Teacher observer 1 – English There are some aspects of Mathematics that are closed (some – Teacher observer 2; some… Teacher Observer 1) but are there not opportunities for problem solving in Mathematics?
	Teacher observer 2 – Mathematics The difference will come in on the methodology… how do you arrive at it… that's the only thing that's open (emmm – general agreement) but the end product (clapping of hands) is closed, is one, (is fact… yes… Teacher Observer 5) (laughter)…(I'm challenging you… Teacher Observer 1 – English Teacher) (laughter…)
	Teacher observer 1 – English No… well I'm not so very comfortable with Mathematics, because I'm a language person, the two are far apart, but I know there are some, just like [the Researcher} is saying, some aspects of Maths that can be open, maybe as you are introducing a topic, probability maybe, when you bring in some issues out there, in order to arrive at (inaudible agreement murmurs), now they have to, the actual calculation (laughter) isn't there something there?
	Teacher observer 2 – Mathematics They'll have, the others will support me, after that (after that… chorus of other teachers) you'll go where you are supposed to go… (yes… chorus) Now when, after that, you will go where you are supposed to go…
	Teacher observer 1 – English Another thing you will use valid questioning techniques… so there at the beginning you have adopted… so depending on what you are doing … the practicality of it…
	Researcher [Teacher Observer 3 and Teacher Observer 4] do you have anything to add?
	Teacher observer 3 - ICT So for me what I saw was presentation and concept mapping, they all worked well to revise, explain and then summarizing the lesson, it was like presentation, watching and it worked well to explain the process of photosynthesis and also giving a summary,
	Teacher observer 4 - Physics Yes maybe what I can add is that… when we say that when we are questioning we only restrict ourselves to closed questioning, on the thing, there, there is some subjects that are closed, I think we will be making a mistake because I think that the knowledge that we give the students or the knowledge that we acquire, we are supposed to apply it somewhere… so high order thinking questions must be there, almost in all, in all subjects… But something that I did not understand, does the technology give students and teachers access to instructional, instructional resources… (…resources – teacher observer 5). I was wondering, was it supposed to be a list of maybe what they can go and read? I did not understand what it was…
	Researcher What do you think?
	Teacher observer 4 - Physics

TPACK Question Domains	Transcripts Teacher 'talk-back' and 'design thinking' conversation following a live lesson observation: What worked well? What worked less well? What can be improved?
	I thought it was maybe a list of what they are going to (or something like for more information they want to … or… – Teacher Observer 5), yeah…
	Teacher observer 2 - Mathematics I think that's where we should be heading, because even there was another question that was asking about the interaction (a question on the observation sheet) the teacher student interaction with the technology (technology… teacher observer 4), with the technology (; emmm…teacher observer 5), now here it is the teacher interacting with the technology, these ones are interacting by observing what … but as [Teacher Observer 4] is saying, I think we should reach a level (inaudible – teacher observer 5), we should reach a level (inaudible… the internet…teacher observer 5), when you are talking about coming up with the concept mapping (mmm… teacher observer 5), can you give them more references on the same, eh? (yeah… chorus)… so that the student will be able to see more examples, and when they come up even with theirs, they have some baseline on, more examples on the same..
On Technology Content Knowledge (TCK)	**Teacher observer 4 - Physics** Or they can go and read for further reading (eh…) , for further reading (how? – Teacher Observer 5)
	Teacher observer 2 - Mathematics So you should reach… reach a level where we give links (now I have understood it… I was also floating… Teacher Observer 5)
	Lesson Teacher - Biology I was also thinking we could even start from a point where they are able to make a simple flow chart… on their own… you know… they are able to say you bring in water… let light come through… and this is what you form… coming up with a simple flow chart using technology… are they able to do that using the computer… let alone going to the internet… (em… teacher observer 2), as basic as that… yeah…
	Researcher What you have discussed and described now is the process of problem solving, starting with the flow chart, fining information from the links to populate the flow chart, sharing their solutions, evaluating their solutions …
	Teacher observer 4 - Physics Because they will do it themselves… and solve the problem…
On Most Significant Impact (MSI)	**Researcher** Last question on SIPSE, from your point of view as teachers working everyday – can you describe the most significant impact in your practice – what was the impact, who was impacted, how did SIPSE contribute to the impact
	Teacher Observer 4 - Physics I think the most significant one is that, there are things that somebody was not able to explain with words, by now if there is something difficult to explain, you can go to the internet and download, then you will display it for the students to be able to see, and then you internalize in a better way…
	Teacher observer 1 - English I feel that SIPSE has provided variety, I think that is the word I would use to talk about its impact, it has provided variety for the learner, so that for the learner it is no longer predictable how a lesson is going to be, the lesson is going to be a teacher with a piece of chalk and a blackboard, it's not predictable, there is a newness to teaching, and an excitement that has come in, so em… that impacts on the learner. learning is something exciting, and that impacts on the teacher, the teacher becomes more empowered, the teachers has more tools to make use of, so the teacher becomes a better teacher rather than how he has been before…
	Teacher observer 2 - Mathematics I think for me it has em, it has opened a new, a new way of… sourcing, sourcing for information, because of outsourcing for the correct information, em, and also presentation of the same. Eh, initially the teachers were a bit closed, in where to get the information, ah, but now this one has opened up, ah, other sources of information ready for us by the teacher. Em, SIPSE has opened that, now, the teacher is able to get more, in the process the student is also able to get more…and it benefits both the student and the teacher, both in content, and in presentation module, you are able to present using different varieties, and that one makes the students even understand more…
	Lesson Teacher - Biology

TPACK Question Domains	**Transcripts** Teacher 'talk-back' and 'design thinking' conversation following a live lesson observation: What worked well? What worked less well? What can be improved?
	Another thing, I think it has removed fear… from us teachers, we used to have the computers before, but there was a lot of fear on what you can do with it, especially when you go to class… I think nowadays we are more confident, the fear that we had on use of technology is no longer there, I think at the end of the day we become better
	Teacher Observer 3 - ICT Also it has enabled the teachers to learn more questioning techniques where they can apply them in class… and in also in conducting the lesson you can know which questions to be discussed in groups and which to give to individual students…
On Most Significant Impact (MSI)	**Teacher Observer 5 - Chemistry** I think SIPSE is completing the training that was not completed in the University during the BA course (some laughter). Yeah we had the content, but even the teaching methodology, they did not capture so much. And that's why sometimes the students were lost. Yes, you're teaching Chemistry, but some content is too abstract, and you are just teaching a few and you also don't know where to, how to go about it, so after we interacted with these gadgets, sometimes you don't have to sweat, somebody is already sweating in the net (laughter)
	Teacher Observer 4 - Physics Maybe I can say that whatever SIPSE is doing it should be taken to college (yeah… it should be part of the Bed course – subject methods…em – Teacher Observer 5). It would be very hard for teachers who are not on training to invite each other to classrooms – but nowadays (through SIPSE) it's comfortable
	Teacher Observer 2 - Mathematics This one creates more interest, (something new) and in so doing it is easier to invite other teachers, a teacher will learn and start using…
	Researcher Thank you everyone for your time and contributions

Appendix 6.3: Teacher Lesson Plan – Problem-Based Lesson

Problem-Based Lesson
School: C
Date: 22/09/2014
Lesson Teacher: Biology Teacher

Lesson Activity Plan

What is the activity?
Grade: Form 3
Subject: Biology
Lesson Topic: Role of Hormones in Insect Metamorphosis
What is the (learning) objective of the activity? By the end of the lesson the learner should be able to; • Distinguish between complete and incomplete metamorphosis in insects. • Explain the role of hormones in regulating metamorphosis.
Resources used (ICT and non-ICT resources) Laptop, projector, white screen, writing board, students' reference and note books.

How is the activity carried out? Write all the steps (Including questioning and discussion techniques and group work organization)

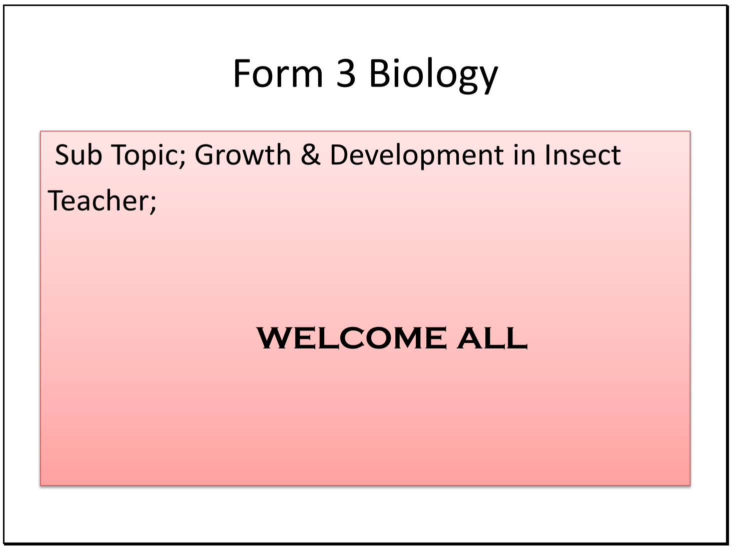
Activity stages	**Activity Description**	**Activity Questions** (write the questions that will be asked at each stage of the activity)
Introduction to the activity	**Step 1:** Teacher reviews concept required for the lesson. • 2 types of life cycles in insects • Activities to differentiate the two types of life cycles. • Details of what happens for the organism to change from one stage to the other.	• To which class do these organisms belong? • Can you give more examples of the members in this class? • What are the main features of the members of this class? • Compare the two types of organism on the slide. What is the name of the first organism? • Do you believe that it is the same organism at different stage of development? • Then how does the organism change from this step to the next

	Activity 2
	• Present the students with a copy on the role of hormones in metamorphosis.
	• Students to read through the copy.
	• Using text boxes, students to link the two hormones to the larval and adult stage of development in a butterfly to see whether students can understand the change
		• What controls the development of the organism from one stage to the other?
		• Which hormone is responsible for the change from larva to pupa?
		• In case of a grasshopper which hormone is produced during;
		  o instar stages
		  o last stage of development

Group work	**Step 3:** Students demonstrates what they have learned in like cycle concept	**Group work** – student applying and analysing type questions

	maps and present any difficulty experienced.	Read through the handouts; • Identify the glands that produce metamorphosis hormones • Link the hormone to the stage of development of the insect using boxes and arrows.
Conclusion to the activity	**Step 4:** Insects display two types of life cycles; complete and incomplete metamorphosis**.** • Complete – has 4 stage, Incomplete 3 stages • Development from one stage to the next is controlled by hormones. • Juvenile hormone prevents moulting. • Ecdysone hormone is responsible for moulting from one stage to the next. • Students take up notes, ask final questions, given assignment to explore further	**Conclusion Questions** – evaluating, creating type questions**:** • Distinguish between complete and incomplete metamorphosis. • What are the roles of juvenile hormone and ecdysone hormones?

Slide 1



Slide 2

Introduction

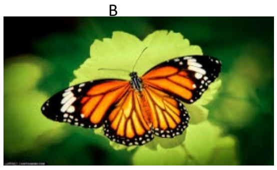
- GROWTH & DEVELOPMENT IN INSECTS

Slide 3

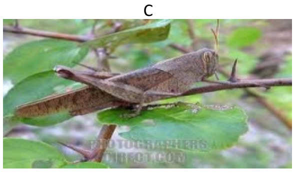
Introduction Con.
Organisms A & B, C & D

A

B



C



D

Slide 4

Complete & Incomplete Metamorphosis

Main Activity

- Life cycle of a grasshopper
- Life cycle of a butterfly
- What controls the development of the organism from one stage to the other?

Slide 5

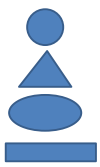
Group Activity
Task 1

Drawing life cycle of insects in groups using pictorials
Group A & Group B the life cycle of a grasshopper
Group C, D & E the life cycle of a butterfly
Use Circles for eggs

Triangle for Larva

Oval for Pupa

Rectangle for adult



Slide 6

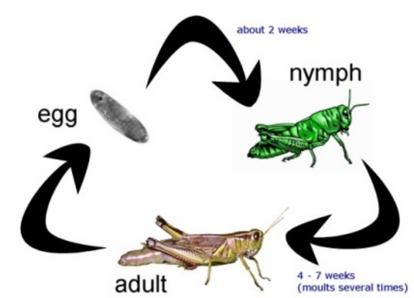
Activity 1

- Group presentations
- Observation of the two life cycles on the slides

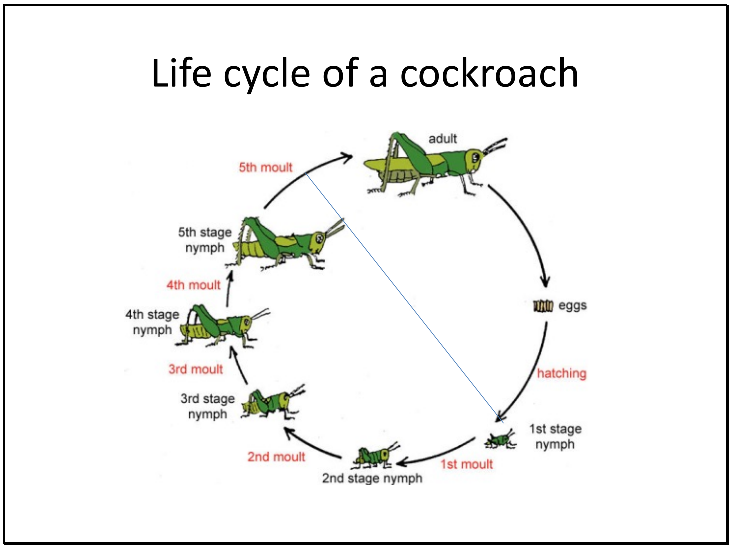
Slide 7

Summarized life cycle of **grasshopper**

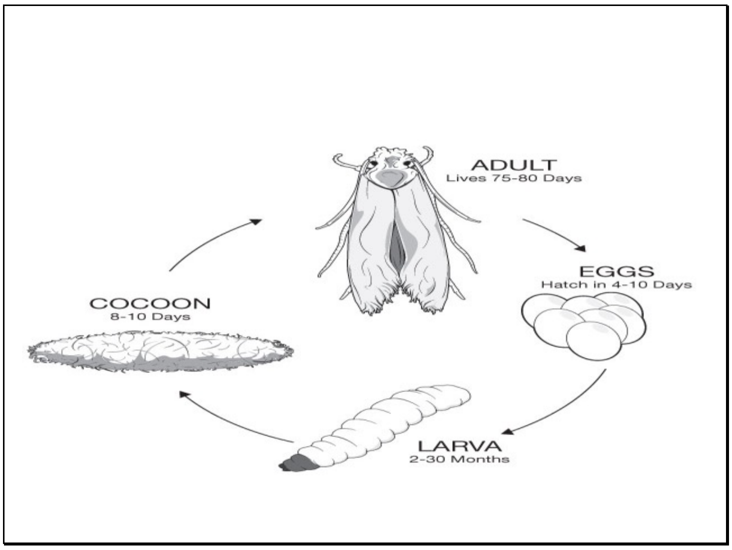
- Incomplete Metamorphosis



Slide 8



Slide 9



Slide 10

Student Activity 2

Group work

Read through the content given then;

- Identify the glands that produce metamorphosis hormones
- The hormones produced
- link the hormone to the stage of development of the insect using boxes and arrows.

Slide 11

Role of Hormones in Insect Metamorphosis

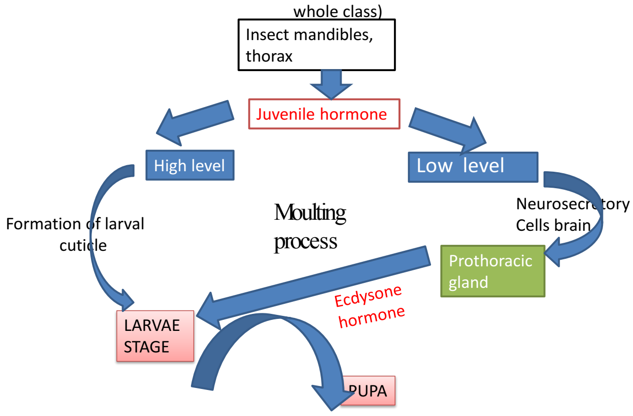
Glands that secrete hormones;

- Neurosecretory cells in brain ganglia
- Corpora allatum –mandibular segments
- Prothoracic glands in thorax

Slide 12

Topic Resource

(Teacher introduces the technology resource and *applying & analyzing* questions. Students complete questions and/ or exercises individually or in groups or with the whole class)



Slide 13

Conclusion

Teacher and students review learning (teacher uses summary *evaluating-creating* type questions)

- Distinguish between complete and incomplete metamorphosis.
- What are the roles of juvenile hormones and ecydson hormone in insect metamorphosis.

Appendix 6.4: Teacher Lesson Plan – Project-Based Lesson

Project-Based Lesson
School: A
Date: 03/02/2015 (Lesson 1); 03/02/2015 (Lesson 2)
Lesson Teacher: Mathematics Teacher

MATHEMATICS
PROJECT BASED UNIT LESSONS
With Webquest Steps

SUBJECT	Mathematics
TOPIC	Loci (form 4)
General Curriculum Objectives: The students will: i. Define locus. ii. Construct different types of loci. iii. Describe the different types of loci.	
Project-based Learning Objectives: The students will: • Use digital tools and other resources to construct different types of loci • Apply loci to real life situations	
Skills:	Develop construction skills and ability to make presentations Develop skills of gathering information from the web
Knowledge	Learn the concept of construction of loci and its application in real life situation.
Attitude	Develop team playing attitude.- i.e. ability to support, share and tolerate other group members' views.
Classroom configuration for ICT use	Classroom/laboratory with a white wall and room for students to work in small groups. Teacher's laptop computer and a projector to aid whole class discussion.
Resources	• Work sheets • Drawing tools i.e. geometrical set • Manila papers • Presentation tool: e.g. MS PowerPoint • GeoGebra Software Application • **Online Resource** 1. www.webmaths.co.uk/**Powerpoint**%20presentations/Shape.../**Loci.ppt** 2. https://urallamaths.wikispaces.com/**Locus**

Lesson 1: The Webquest 'introduction', 'task', 'process' and 'guidance'

LESSON PLAN ACTIVITIES **The lesson is divided into 3 main activity stages – Introduction, Main Activities, Conclusion**	
LESSON ACTIVITIES	**Activities -** the teacher walks the student through each stage of the webquest – using the webquest presentation that the teacher created
Introduction	**The Introduction – the 'hook'** • Teacher and students brainstorms practical scenarios of loci in the surrounding **Guidance** • Teacher guides students to recall different constructions of basic geometrical figures
Main activities *New knowledge*	**The Task** • Students will be placed in collaborative groups of 6-7 to research and construct different loci in a work sheet

LESSON PLAN ACTIVITIES The lesson is divided into 3 main activity stages – Introduction, Main Activities, Conclusion	
	Components of the task: The students in each group will construct the different loci in the work sheet and make presentations of their work using manila papers • Look for different scenarios where loci can be applied to real life **Resources** 1. www.webmaths.co.uk/**Powerpoint**%20presentations/Shape.../**Loci.ppt** 2. https://urallamaths.wikispaces.com/**Locus** The team makes whole class presentation of their work.
Reinforcement	**The Process** • The groups will decide from their research what to include under the various components of the portfolio they are developing on cubic functions. • They will develop an artefact based on the concept of cubic function. For example the teacher can show to students an open-top box out of a piece of cardboard that is 50 cm by 40 cm from which a cubic function can be deduced to represent the volume of the box. • Groups will be allowed to determine the dimensions of the cardboard themselves to investigate further to develop the artefact which will model the concept of the exact cubic function. **Guidance** The team will create a response to the following questions. i. Which tools do you use for the constructions ii. How can you describe the shapes that you constructed iii. Why is it important to show the arcs of construction iv. Explain where you can apply the knowledge of loci in real life **The team will prepare 7 minutes presentation of their work.**
Conclusion & homework	Students will make their group product – during the class and/or as homework • Students will chose whether they are making a presentation slide show, (ICT) or a wall chart or blackboard/ whiteboard or copy book pages (non-ICT) presentation • Students can also include images and/or spreadsheets and/or GeoGebra diagrams and / or You Tube clips from the internet or that they have drawn in their Presentation

Lesson 2: The webquest student 'product' presentation and 'evaluation'

LESSON PLAN ACTIVITIES The lesson is divided into 3 main activity stages – Introduction, Main Activities, Conclusion	
LESSON ACTIVITIES	**Activities -** the teacher walks the student through each stage of the webquest – using the webquest presentation that the teacher created
Introduction	**The Product** i. The group will make presentation on their work product and whole class will comment on it. ii. The group members will answer questions from other group members. -
Main activities *New knowledge*	**Reflection on the product** The group members will answer these questions following the group presentations: - What new information did you learn about locus? - Name one thing that you think this team did well in making their constructions - Which real life application of loci did your team select? - How are these applications useful in everyday life?
Assessment	**Evaluation** • Students will be assessed on the group portfolio product presentation and on the answers to the discussion questions that they answered during the presentation

LESSON PLAN ACTIVITIES **The lesson is divided into 3 main activity stages – Introduction, Main Activities, Conclusion**	
	• Team presentations will be assessed on content and design using a rubric created by the teacher and / or the class

	16 - 20	**11 - 15**	**6 - 10**	**1 - 5**	**Score**
Organization	Presentation is well organized, neat and communicates very clearly the topic information	Presentation communicates clearly topic information – but needs spoken explanation	Presentation communicates quite clearly topic information – but needs a lot of spoken explanation	Presentation does not clearly communicate the topic information – even with spoken explanation	
Quality of content	Answers all questions very well and contains other interesting facts or conclusions	Answers all questions well	Answers some questions well	Answers very few questions or none at all	
Quality of group presentation	Presentation visuals and effects are very effective and improve the content – – and do not distract from the content	Visuals and effects in the presentation are effective - – and do not distract from the content	Visuals and effects in the presentation are quite effective – and do not distract from the content	Visuals and effects in the presentation are not effective – and they are distracting from the content	
Quality of group research	Group can organize, analyse and synthesize information from a variety of sources	Group can organize, analyse and with help can synthesize information from a variety of sources	Group can with help organize and analyse information from a variety of sources	Group has difficulty to organize and analyse information even with help	
Quality of group communication	Group members interact, collaborate and work effectively together to produce an original project	Group members with some teacher guidance can work collaborative and effectively together to produce an original project	Group members with a lot of teacher guidance can work collaboratively and effectively together to produce an original project	Group members have difficulty to work collaborate and effectively together even with teacher guidance	
				Total score	

See Rubistar on how to make a rubric at: http://rubistar.4teachers.org/

Follow-up

- Students present their presentations to other classes in the school/ to members of the community/ to other schools
- Teachers conduct an inter-school webquests for school visits

Follow-up	What new thing will do if you are another opportunity to do the same project?

STUDENT WORK SHEET - LOCI

1. Construct the locus of points 4.5 cm from a point O

   Describe the locus.

2. Construct the locus of a point such that it is equidistant from two points, P and Q, 6 cm apart

   Describe this locus.

3. Draw a line segment AB, 5.5 cm. Construct the locus of a point Q such that it is always 3 cm from AB.

   Describe the locus

   Construct two line segments AB = AC = 6.2 cm and $\angle BAC = 60°.$ Construct the locus of a point P such that it is equidistant from AB and AC. Describe the locus

4. Draw a line segment XY = 4.2 cm. referring to your knowledge of angle properties of a circle, draw the locus of a point Z, such that $\angle XZY = 90°$

5. List down and explain areas where Loci can be applied in real life.

Resources:

1. Secondary mathematics bk 4
2. www.webmaths.co.uk/**Powerpoint**%20presentations/Shape.../**Loci**.**ppt**
3. https://urallamaths.wikispaces.com/**Locus**
4. Geometrical sets
5. Manila papers

Loci Revision Slides

Slide 1

Revision

Construction using compasses

Slide 2

Loci

Objectives:

- Understand the idea of a locus
- Construct accurately loci, such as those of points equidistant from two fixed points
- Solve loci problems, such as identifying points less than 3cm from a point P.
- Describe the figures constructed from loci

Prior knowledge:

Construct the perpendicular bisector of a line

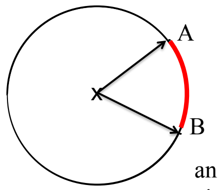
Construct the bisector of an angle

Slide 3

Construction using compasses

Construction using compasses works because all the points on the radius of a circle are exactly the same distance away from the centre of the circle.

Point B is exactly the same distance away from the centre of the circle as Point A.



Equidistant means:
The same distance from

So: A and B are equidistant from X

an Arc is a part of a circle circumference.

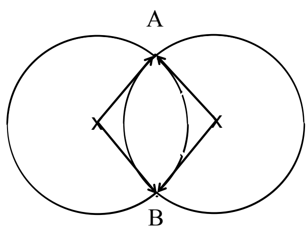
So: the circumference segment AB is an arc.

Slide 4

Construction using compasses

This means that for 2 circles that overlap – if the circles are the same size, the points where they cross are the equidistant from the circle centres

Point A is equidistant from the centres of both circles



Point B is also equidistant from the centres of both circles

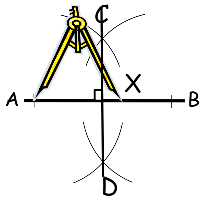
Slide 5

Construction using compasses

Constructing the bisector of a straight line segment.

Bisector

two section — means cutting the straight line in two equally sized sections



Draw the line segment AB making sure that it has two very distinct ends

N.B you must always Show the construction arcs

Now draw a straight line from C to D.
The line crosses AB at X which is the mid-point of AB

The line CD is the perpendicular bisector of AB

Slide 6

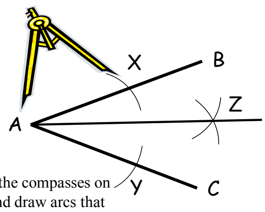
Construction using compasses

Constructing the bisector of an angle.

Bisect angle BAC N.B. The vertex of the angle is always the middle letter

Set the radius of the compasses to about half way along the lines

Put the point of the compasses on point A and draw two arcs to cut AB and AC



Put the point of the compasses on X & Y in turn and draw arcs that intersect at Z

This identifies two points X & Y equidistant from point A

N.B you must always Show the construction arcs

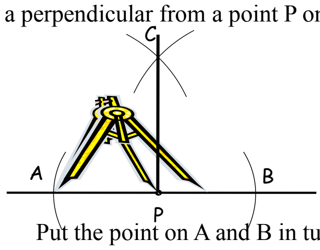
Draw a line from A to Z – this is the bisector of the angle

This works for any kind of angle acute, obtuse or reflex

Slide 7

Construction using compasses

Constructing a perpendicular from a point P on a line segment.



Put the point on A and B in turn and draw arcs that intersect at C

Put the point of the compasses on P, draw 2 arcs to cut the line segment at A and B

Notice that once points A and B have been found the construction is identical to finding the perpendicular bisector of the line. Why?

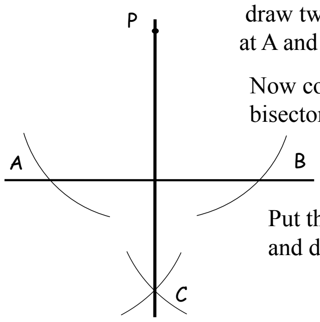
Slide 8

Construction using compasses

Constructing a perpendicular from a point P onto a line segment.

With the point of the compasses on P, draw two arcs that intersect the line at A and B

Now construct the perpendicular bisector as before



Put the point on A and B in turn and draw arcs that intersect at C

Join CP. CP is the perpendicular to the original line with a 90° angle at P

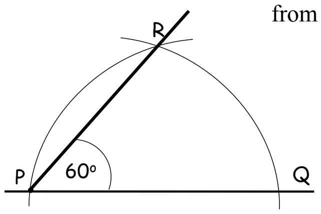
Slide 9

Construction using compasses

Constructing an angle of 60°.

Because the same radius was used
P, R and Q are all equidistant
from each other.

Equilateral triangle
The internal angles
in an equilateral triangle are
all 60°



Draw a large arc that intersects the line at Q
Keeping the radius the same and draw an arc from Q that intersects
at P and crosses the other arc

Loci Webquest Slides

Slide 1

- **SUBJECT:** Mathematics
- **Topic:** Loci
- **LEVEL:** Form Four
- **Prepared by:** Lesson Teacher Mathematics, School A

Slide 2

INTRODUCTION

In this activity your group will be expected to

- investigate the properties of loci using Internet Resources and Geogebra software
- construct different forms of loci in a worksheet
- apply the concept of loci to solve real life problem

Slide 3

TASK

- You will work in small groups (6-7 members in each group) to research and construct different loci in a worksheet

Slide 4

Components of the task:

The student portfolio to be produced by each group must include the following.

- Construct the different loci in the work sheet and make presentations of their work using manila papers
- Look for different scenarios where loci can be applied to real life

Slide 5

PROCESS

- Members of each group will gather information from the websites to create new ideas about loci and how they can be applied in real life
- Group members can use non-ICT tools (geometry set) and ICT tool (GeoGebra software) to construct the different loci on a worksheet

Slide 6

PROCESS

- They will develop an artifact based on the ideas of cubic function they have gathered.
- Group members will: research and develop constructions based on the following worksheet outline:
    - Construct the locus of points 4.5 cm from a point O
    - Describe the locus.
    - Construct the locus of a point such that it is equidistant from two points, P and Q, 6 cm apart
    - Describe this locus.
    - Draw a line segment AB, 5.5 cm. Construct the locus of a point Q such that it is always 3 cm from AB.
    - Describe the locus
    - Construct two line segments AB = AC = 6.2 cm and ∠BAC=60°. Construct the locus of a point P such that it is equidistant from AB and AC. Describe the locus
    - Draw a line segment XY = 4.2 cm. referring to your knowledge of angle properties of a circle, draw the locus of a point Z, such that ∠XZY=90°
    - List down and explain areas where Loci can be applied in real life.

Slide 7

Webquest resources

- Secondary mathematics bk 4
- Topics in Mathematics - Loci at: http://www.webmaths.co.uk/hgcsesowindex.html
- Mathematics notes on Locus at: https://urallamaths.wikispaces.com/Locus
- Manila papers
- GeoGebra Software at: http://www.geogebra.org/download

Slide 8

GUIDELINE

The team will create a response to the following questions.

- Which tools do you use for the constructions
- How can you describe the shapes that you constructed
- Why is it important to show the arcs of construction
- Explain where you can apply the knowledge of loci in real life

Slide 9

GUIDELINE

- You can chose whether you are making a presentation slide show, (ICT) or a wall chart or blackboard/ whiteboard or copy book pages (non-ICT) presentation
- You can also include images and/or spreadsheets and/or geogebra diagrams and / or You Tube clips from the internet or that they have drawn in your Presentation

Slide 10

CONCLUSION

- The group will make presentation on their work product and whole class will comment on it.
- The group members will answer questions from other group members.

Slide 11

Conclusion……..

- Concluding questions will base on:
- What new information did you learn about locus?
- Name one thing that you think this team did well in making their constructions
- Which real life application of loci did your team select?
- How are these applications useful in everyday life?

Slide 12

Evaluation

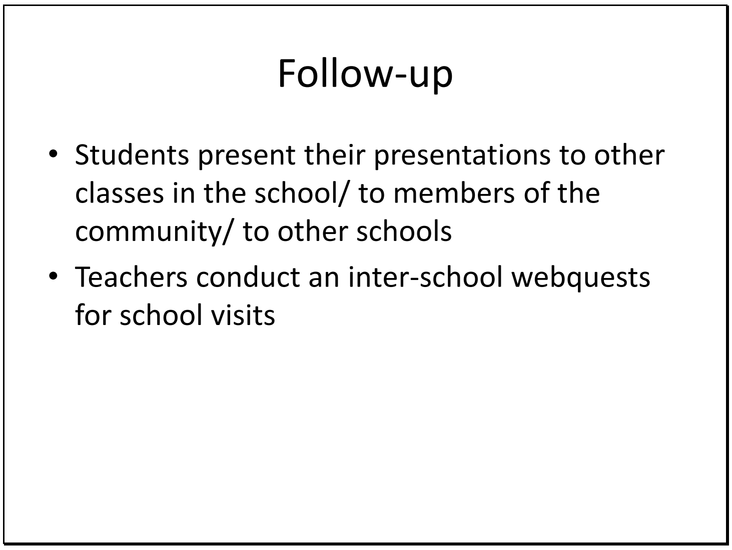
Evaluation	Exceptional 16 – 20 marks	Very good 11 – 15 marks	Satisfactory 6 – 10 marks	Poor/ needs work 1 – 5 marks	Total Score
Organization	Presentation is well organized, neat and communicates very clearly the topic information	Presentation communicates clearly topic information – but needs spoken explanation	Presentation communicates quite clearly topic information – but needs a lot of spoken explanation	Presentation does not clearly communicate the topic information – even with spoken explanation	
Quality of content	Answers all questions very well and contains other interesting facts or conclusions	Answers all questions well	Answers some questions well	Answers very few questions or none at all	
Quality of group presentation	Presentation visuals and effects are very effective and improve the content – – and do not distract from the content	Visuals and effects in the presentation are effective - – and do not distract from the content	Visuals and effects in the presentation are quite effective – and do not distract from the content	Visuals and effects in the presentation are not effective – and they are distracting from the content	

Slide 13

Evaluation

Evaluation	Exceptional 16 – 20 marks	Very good 11 – 15 marks	Satisfactory 6 – 10 marks	Poor/ needs work 1 – 5 marks	Total Score
Quality of group research	Group can organize, analyze and synthesize information from a variety of sources	Group can organize, analyze and with help can synthesize information from a variety of sources	Group can with help organize and analyze information from a variety of sources	Group has difficulty to organize and analyze information even with help	
Quality of group communication	Group members interact, collaborate and work effectively together to produce an original project	Group members with some teacher guidance can work collaborative and effectively together to produce an original project	Group members with a lot of teacher guidance can work collaboratively and effectively together to produce an original project	Group members have difficulty to work collaborate and effectively together even with teacher guidance	
				Total score	

Slide 14


Follow-up
• Students present their presentations to other classes in the school/ to members of the community/ to other schools
• Teachers conduct an inter-school webquests for school visits

Appendix 6.5: Extract Lesson Observation – Problem-Based Lesson

Problem-Based Lesson
School: D
Date: 25/09/2014
Lesson Teacher: English Teacher

Teacher Observers:
Teacher Observer 1 - English Literature;
Teacher Observer 2 – Mathematics/ Physics;
Teacher Observer 3 – Biology;
Teacher Observer 4 - Physics;
Teacher Observer 5 – Chemistry

Background Information	
Which class or form are you observing?	Form 4
What is the subject being taught?	English
How many students are in this class?	55+
How many boys are in the class?	55+
How many girls are in the class?	0
Date of the Lesson Observation	25/09/2014
Time of the Lesson Observation	11:00 - 1140
What were the teacher's objectives in the lesson?	Be able to write topic sentence; be able to write supporting sentences; be able to write clincher or concluding sentences
What were the teacher's classroom arrangements throughout the lesson?	Rows as lesson took place at desk of science lab
What technology resources were present in the classroom?	- Excelling in English book four page 9 – 10; - Laptop and projector – for classroom work; - Computer lab – for group work in the lab; - Video clips (two) of students performing a small skit; - Clips from you tube: Writing better paragraphs.mp4; Writing Effective Paragraphs.mp4; - Activity mind concept sheet for group work in the lab and individual home work

Lesson Teacher Self-Reflection
Content Knowledge (CK) - student learning of topic concepts- **A. What do you think your pupils learned from the topic?** They learned how to write paragraph effectively
B. How can you tell? They answered the questions well, the group presentation, the paragraphs were good.
C. Were there any unexpected things that happened? The students reacted well to the home produced video of the teacher
Technology (TK): Resources (both ICT and non-ICT) **A. How do you think your ICT and non-ICT resources that you used in your lesson contributed to your students' understanding of the topic concepts?** - Non-ICT resources - Excelling English Book 4 - pg 9; blackboard; whiteboard; - ICT resources - laptop, projector - ICT activity - the student's clip - small skit, helped them construct sentences

Lesson Teacher Self-Reflection
B. How can you tell? They were able to identify topic, support & clincher sentences
Pedagogy (PK): Strategies - 'questioning' or 'promoting discussion' or 'group work' or 'real world problem solving' **A. How effective do you think were your pedagogical strategies for supporting your students learning?** - Questioning, group discussion - They were able to write better paragraphs
B. How can you tell? - Questions catered to all learners - They participated well
Technology, Pedagogy and Content Knowledge (TPACK) - Lesson Teacher - How well did the pedagogical strategies (didactic or problem based strategies) and technology (ICT & Non ICT) 'fit' together in the lesson? - The pedagogy and technology fitted together to support lesson - Video clips , the textbook and group work supported the curriculum learning objectives - It needs more time e.g. a lesson of 80 minutes

Name of teacher observer:	Teacher Observer 2 – Mathematics/ Physics
Content Knowledge (CK) - learning objectives, 'hook' (story or problem or information), concepts, skills & procedures **A. What did you see?** - The teacher introduces the topic with a hook in the form of a video clip - The topic of study is introduced (paragraph structure) - In form of PowerPoint Presentation the teacher provides appropriate information about the topic of study - During the lesson the teacher asks the students questions and students respond with answers - Students are divided into eight groups, given assignments to do and present it later to the class - Further reading is given at the conclusion	
B. What did you think - worked well/ less well? - The video clip (hook) did get the students in the right mood of the lesson and also captures students attention - Lesson skills presentation was well in line with the lesson topic - The group discussion among students worked well and they were able to present their findings well - However the lesson objectives were not explained to the students - The video clip could have been delayed	
Technology & Content Knowledge (TCK) - ICT (spreadsheets or presentation or word or concept mapping or other); Non-ICT (worksheets, blackboard, texts, assessment, creative/ innovative tasks/ projects) **A. What did you see?** - Technologies used included laptop, projectors, noticeboard, PowerPoint presentation, group work tasks and group work presentation - The teacher used ICT to project the lesson content and activities - The students made observations and the lesson progressed - The technology excited the students and made them more attentive and made the class more interactive	
B. What did you think - worked well/ less well?	

Name of teacher observer:	Teacher Observer 2 – Mathematics/ Physics
- The use of ICT in the lesson enhanced understanding of the lesson topics - More time could be allowed for the group discussion session - A variety of video clips could be used	
Technology and Pedagogy (TPK) - questioning (remembering understanding, analysing, applying, evaluating and creating type questions), Group work (same task/ different tasks), Problem solving (task definition, identify & gather resources, analyse, synthesize, evaluate), Technology (ICT & non-ICT) **A. What did you see?** - The teacher made use of some group work - The teacher engages the students on analysing type questions (what can you see on the video clip?) - The technology did help the students to interact in a question and answer method	
B. What did you think - worked well/ less well? - The same group tasks worked well as it saved time and also ensured the same level of content is observed by students - Questions could be made to cover more levels by applying, evaluating and creating type questions	
Technology, Pedagogy and Content Knowledge (TPACK) - How well did the pedagogical strategies (didactic or problem based strategies) and technology (ICT & Non ICT) 'fit' together in the lesson? **A. What did you see?** - The teachers pedagogy and strategy did fit well with the presentation used - The teacher used problem-based learning at the beginning of the lesson - It did fit with the lesson objective	
B. What did you think - worked well/ less well? - The technology & activity did allow students to build higher order thinking skills i.e. problem solving	

Appendix 6.6: Extract Lesson Observation – Project-Based Lesson

Project-Based Lesson
School: B
Date: 03-04/02/2015
Lesson Teacher: Mathematics Teacher (School B)

Teacher Observers:
Teacher Observer 1 - English Teacher (School B)
Teacher Observer 2 – Chemistry Teacher (School A);
Teacher Observer 3 – Biology Teacher (School A);
Teacher Observer 4 – Mathematics (School A);

Background Information	
Which class or form are you observing?	Form 4
What is the subject being taught?	Mathematics
How many students are in this class?	45
How many boys are in the class?	0
How many girls are in the class?	45
Date of the Lesson Observation	03/02/2015 (1st lesson) – 04/02/2015 (2nd lesson)
Time of the Lesson Observation	10:50 – 11:30 (1st lesson) – 12:20 – 13:00 (2nd lesson)
What were the teacher's objectives in the lesson?	Graph trigonometric functions and determine their properties
What were the teacher's classroom arrangements throughout the lesson?	Students in rows for whole classwork and then divided into groups around computers for webquest tasks and then group presentations in plenary
What technology resources were present in the classroom?	- Textbooks, manila paper, PowerPoint presentation, - You Tube, GeoGebra software

Name of teacher observer:	**Teach Observer 1 – English**
Content Knowledge (CK) - learning objectives, 'hook' (story or problem or information), concepts, skills & procedures **A. What did you see?** - The students present their findings as others listen & pose questions. - The teacher observes & clarifies issues - The students were well guided by the teacher on the task at hand	
B. What did you think - worked well/ less well? - All the students were attentive & very interested - Students presenting fielded questions quite well	
Technology & Content Knowledge (TCK) - ICT (spreadsheets or presentation or word or concept mapping or other); Non-ICT (worksheets, blackboard, texts, assessment, creative/ innovative tasks/ projects) **A. What did you see?** - Technology used was GeoGebra software - Mostly derived their concepts from non-ICT resources	
B. What did you think - worked well/ less well? - It makes the learners connect any missing links - The resources were well utilised	
Technology and Pedagogy (TPK) - questioning (remembering understanding, analysing, applying,	

Name of teacher observer:	Teach Observer 1 – English
evaluating and creating type questions), Group work (same task group work webquest/ different task group work webquest), Project based learning (introduction, define task, process, guidance, product presentation, rubric evaluation, conclusion and follow-up), Technology (ICT & non-ICT) **A. What did you see?** - The questions were on analysis and application i.e. students were asked if it were possible to get the 'period' from the equation given. - The teacher gave different for different groups	
B. What did you think - worked well/ less well? - The students were quite ready for it - All the groups handled their area well	
Technology, Pedagogy and Content Knowledge (TPACK) - How well did the pedagogical strategies (didactic or problem based strategies) and technology (ICT & Non ICT) 'fit' together in the lesson? **A. What did you see?** - The strategy used by the teacher merged a number of pedagogical strategies - The questioning made the students practice higher order thinking	
B. What did you think - worked well/ less well? - It was appropriate for the topic being concerned	

Webquest Assessment Criteria	**Level** Fair 1-5; Satisfactory 6-10; Good 11 – 15; Excellent 16 - 20	**Comments**
Organization	Excellent - 17	The charts were well illustrated and sequential
Quality of content	Excellent - 17	Mathematical facts were well stated & explained
Quality of group presentation	Excellent - 17	The presentation was clear and to the point
Quality of group research	Excellent - 17	Data presented is quite accurate
Quality of group communication	Excellent - 18	All members of the group were involved in the presentation and worked like a tag team - a very good presentation

Appendix 6.7: Teacher Questionnaire Transcript

Project-based Lesson
School: A
Date: 17/03/2015
Lesson Teacher: Mathematics Teacher

Part 1: Use of ICT in teaching and learning		
Main Question	**Probes**	**Teacher Responses**
1. Goals What are your ideas / approaches about teaching and learning in your subject area of Mathematics?		
	• What is your objective for using ICT in your Mathematics teaching?	My main objective is to make mathematics more interesting to the learners and also engage the learners more actively involving them in the learning activities
	• How has your objective for using ICT changed since you started in the SIPSE course?	Yes. I have slightly modified my objective as before the SIPSE course, I mainly used ICT as a demonstration tool, but I've come to realise that the learners too can interact very effectively with the technology.
	• What did you find most valuable about the SIPSE professional development modules?	I think the most profound discovery was the resources I have at my disposal on the web. They are simply mind boggling!
	• Do you plan to go on using ICT in your teaching? If so, in what ways?	Of course I plan to continue using ICT in my teaching. I'm currently engaged in a campaign to make the classrooms more ICT friendly with my Principal. I hope to change the mind set of my colleagues as well as the students to buy into the idea of ICT integration.
	• What general activity ideas or lesson planning activity ideas from the modules did you bring back to your classroom practice?	The most important one is planning on my questioning technique. The importance of planning for the type of questions to ask cannot be gainsaid.
2. Tools What are the ICT tools that you use in the teaching/learning process? (e.g. admin tools, practice and drill, presentations, word, spreadsheets, simulations, webquests, concept mapping, the internet, laptops, projectors, mobile phones etc.)		
	• What non-ICT tools - methods do you apply when using ICT in teaching and learning? (e.g. charts, school texts, blackboard/ chalk, pedagogical strategies - to promote discussion, questioning, collaborative learning, group work etc.)?	The chalk board mostly and charts occasionally.
	• How often do you use ICT to teach Mathematics – please indicate which of the following: o Every day? o Once a week? o Once a month? o Never?	Once a week

Part 1: Use of ICT in teaching and learning		
Main Question	**Probes**	**Teacher Responses**
	• What kinds of barriers have you encountered with using technology in your Mathematics lessons after the SIPSE training?	Limited equipment and undeveloped ICT infrastructure in the classrooms.
	• How have you addressed these challenges	We are trying to address them through our ICT school policy by trying to change our classrooms into ICT friendly rooms.
3. Rules and regulations Are there rules set by the school about using ICT in your classroom practice - that influence how you use ICT in your Mathematics teaching?		There are no rules as yet. However we are thinking of setting up a minimum threshold for ICT use in our classrooms for all teachers.
	• Standard setting –what are the criteria that you use when evaluating the learning of your students?	Evaluation is usually done as per the syllabus coverage.
	• Do the criteria change in the classes where you use ICT? • Do you develop new criteria for these classes?	This criteria does not change for classes where ICT has been used and no new criterion has been developed
	• Do the national examinations influence how you use ICT? • Do the national examination influence what you 'try out' with ICT in the classroom?	The national examinations do not really influence my ICT use, but rather, the topic at hand.
4. Roles and responsibilities What kinds of different roles/ responsibilities do you/ your pupils have in class when using ICT?		I mostly come up with the content and use ICT for presentation mostly. But I've also started letting the learners engage with technology by giving them ICT based assignments
	Training Support Role • How do you see that the ICT-STEM training assisted you in integrating technology in your teaching? • Is it changing your role as a teacher? Explain how it is/ or is not changing your role	The STEM training has been very instrumental in guiding me in getting materials for my learners from the web and also developing content especially using GeoGebra It is changing my role as a teacher because with the right questions for the learners I'm becoming more of an observer as the students take up the role of discovering for themselves
	School Support Role • How does the school support ICT use in the SIPSE programmes/ classroom work? • Does the school administration support you in the use of ICT in classroom practice? Explain	The school has been very supportive in providing the basic infrastructure for ICT integration, e.g. computers, laptops, projectors and most important 24/7 internet connection
	Technical support Role • Have you encountered difficulties in using the laptop and project	There are difficulties in using laptops because one has to keep carting them from one class to the other and this consumes inordinate amount of time

Part 1: Use of ICT in teaching and learning		
Main Question	**Probes**	**Teacher Responses**
	technology in your Mathematics teaching?	
	Student role • How do you think the ICT SIPSE training and programmes have benefitted your students' learning? • What kinds of different responsibilities do you see your students doing in your Mathematics classes where you are using ICT? • What can you tell about how students use technology outside class or school hours?	I think we are slowly making our learners into the 21st century citizens by giving relevant skills to use the advanced tools we have The learners are able to set their own questions using ICT and sometimes using the same tool to solve some problems I'm increasingly seeing our learners do research from the web
5. Community	What kind of collaboration is there among teachers in the school about SIPSE use of ICT in teaching and learning?	We have teachers even in other non-STEM subjects consulting on how they can use ICT in their classes
	Is there any collaboration with teachers in other SIPSE Schools? Explain	We do exchange materials with our immediate neighbours—School B

Appendix 7: Ethics Approval, Research Permission and Consent Forms

Appendix 7.1: Ethics Approvals – Queen's University Belfast

Queen's University Belfast

School of Education
Queen's University Belfast
20 College Green
Belfast
BT7 1LN
Tel +44 (0) 28 90975923
www.qub.ac.uk

Memorandum

To	Mary Hooker
From	Katrina Lloyd, Chair, Ethics Committee
Date	2 September 2015
Distribution	Supervisor School of Education Office File
Subject	Ethics Approval for Research Proposal "'A Study on the implementation of the Strengthening Innovation and Practice in Secondary Education initiative for the preparation of Science, Technology, English and Mathematics (STEM) Teachers in Kenya ..." (submitted 11.11.14)

The School of Education Ethics Committee has approved your proposed research.

Note that this approval applies only to the procedures outlined in your submission.

Any departure from these must be discussed with your supervisor, and may require additional ethical approval.

Note for the supervisor: it is the responsibility of the supervisor to add any research projects involving human participants, material or data, to the University's Human Subjects Database for insurance purposes. (The Human Subjects Database is accessible through QOL under 'My Research').

The Committee wishes you every success with your research.

Queen's University Belfast

School of Education
Queen's University Belfast
20 College Green
Belfast
BT7 1LN
Tel +44 (0) 28 90975923
Fax +44 (0) 28 90971084
www.qub.ac.uk

Memorandum

To	Mary Hooker
From	Katrina Lloyd, Chair, Ethics Committee
Date	10 January 2014
Distribution	Supervisor School of Education Office File
Subject	Ethics Approval for Research Proposal "A Study on the implementation of the Strengthening Innovation and Practice in Secondary Education ..." (submitted 4.12.2013)

The School of Education Ethics Committee has approved your proposed research.

Note that this approval applies only to the procedures outlined in your submission.

Any departure from these must be discussed with your supervisor, and may require additional ethical approval.

Note for the supervisor: it is the responsibility of the supervisor to add any research projects involving human participants, material or data, to the University's Human Subjects Database for insurance purposes. (The Human Subjects Database is accessible through QOL under 'My Research').

The Committee wishes you every success with your research.

Appendix 7.2: Research License -NACOSTI, Kenya

NATIONAL COMMISSION FOR SCIENCE, TECHNOLOGY AND INNOVATION

Telephone: +254-20-2213471, 2241349, 310571, 2219420
Fax: +254-20-318245, 318249
Email: secretary@nacosti.go.ke
Website: www.nacosti.go.ke
When replying please quote

9th Floor, Utalii House
Uhuru Highway
P.O. Box 30623-00100
NAIROBI-KENYA

Ref: No.

Date:

4th June, 2014

NACOSTI/P/14/9257/1050

Mary Rose Hooker
Queen University Belfast
UK.

RE: RESEARCH AUTHORIZATION

Your letter dated 23th May 2014 refers.

Your request to include Nakuru County on your research titled ***"A study of the SIPSE Initiative for the preparation of stem by secondary teachers in Kenya to integrate ICT in teaching and learning"*** for permit number NACOSTI/P/14/9257/1050 is granted.

You are advised to report to **the County Commissioner and the County Director of Education, Nakuru County** before embarking on the research project.

On completion of the research, you are expected to submit **two hard copies and one soft copy in pdf** of the research report/thesis to our office.

SAID HUSSEIN
FOR: SECRETARY/CEO

Copy to:

The County Commissioner
The County Director of Education
Nakuru County.

Appendix 7.3: Research Affiliation - Kenyatta University, Nairobi, Kenya

KENYATTA UNIVERSITY

OFFICE OF THE VICE-CHANCELLOR

Tel: (+254-20) 8710901-19
Fax: (+254-20) 8711575
Cell: 0734 766486
Website: www.ku.ac.ke

P. O. Box 43844-00100
Nairobi, Kenya
Email: vc@ku.ac.ke

REF: KU/VC/IRST/B6/VOL.1

DATE: 21ST JANUARY 2014

Mary Hooker
School of Education
Queen's University Belfast
University Road
Belfast BT7 1NN
Northern Ireland, UK

Dear Madam,

RE: REQUEST FOR AFFILIATION

The above subject refers.

Your request for affiliation to Kenyatta University to enable you conduct research on ***"A Study on the Implementation of the Strengthening Innovation and Practice in Secondary Education (SIPSE) initiative for the preparation of Science, Technology, English and Mathematics (STEM) Teachers in Kenya and Tanzania to integrate Information and Communication Technology (ICT) in Teaching and Learning"***, is approved on the understanding that you will;

- Share knowledge in forums with Kenyatta University in conjunction with the universities you are affiliated with in Ireland.
- Give lectures to the students in the School of Education
- Invite participation from the School of Education representative in the policy workshops related to the research and outputs of the Strengthening Innovation in Secondary Education in Kenya.

Once in Kenyatta University, make arrangements with the Dean, School of Education for the above to be achieved. Further, make sure that you get the appropriate government research permit which is a requirement for all researchers in Kenya.

The library space at Kenyatta University is available for use when conducting out your research. You will be expected to deposit a hard and soft copy of your research report with the Kenyatta University Institute for Research, Science and Technology on conclusion of your project.

Yours sincerely,

Omugenda

PROF. OLIVE M. MUGENDA, Ph.D, EBS, CBS
VICE-CHANCELLOR

Encl.

Kenyatta University ...ISO 9001:2008 Certified

Appendix 7.4: Informed Consent Forms

Research on the *Strengthening Innovation and Practice in Secondary Education* (SIPSE) Schools in Kenya

INFORMATION STATEMENT

I. Introduction to the Research Study

I am conducting research on the use of ICT to support teacher development and classroom practice in the *Strengthening Innovation and Practice in Secondary Education* (SIPSE) initiative for the preparation of Science, Technology, English and Mathematics (STEM) Teachers in Kenya.

The research I wish to conduct will be part of the requirements for completing my Education Doctorate in Queen's University Belfast (QUB), Northern Ireland. The research report will be published in the form of a Doctorate Dissertation and may be presented in scholarly and professional conferences and in scholarly and professional papers. The research proposal has been submitted, reviewed and approved by the QUB Ethics Committee.

You are invited to take part in a research study to evaluate the use of ICT to support teacher development and classroom practice in the SIPSE project.

The study has the title: A Study of SIPSE Initiative for the preparation of Science, Technology, English and Mathematics (STEM) Science, Technology, English and Mathematics teachers in Kenya to integrate ICT in teaching and learning.

The research purpose: to evaluate the use of Information and Communication Technology (ICT) to support teacher development and classroom practice in secondary schools in Kenya.

Approval to carry out the research in Kenya has been obtained from the Kenya National Commission for Science, Technology and Innovation. Approval for linking the research with a Kenyan University has been approved by the Kenyatta University, Nairobi.

Ethical approval for the research has been obtained from the Queen's University, Belfast, Northern Ireland.

Researcher: I am Mary Hooker. I am the researcher of this study. My email address is: mary.hooker@gesci.org

II. Details of what involvement in the research will require

For teachers

During **the SIPSE course** you will be invited to complete questionnaires, to contribute to chats and discussions and complete lesson plans journals and observations on the use of ICT in your teaching.

As a **participant in the research study** means that data about you in the SIPSE course may be used for the purposes of the research – such as your questionnaire responses, your contribution to chats and discussions and your lesson plans journals and observations.

As a **participant in the research study** you may be invited to take part in interviews and/ or focus group discussions as a follow-up to questionnaires and observations

For head teachers
As a **participant in the research study** you may be invited to take part in interviews

III. Benefits (direct or indirect) to participants from involvement in the Research Study

Your participation in this study will help to inform how ICT can be used as an instructional tool in the teaching and learning of STEM subjects in secondary schools in Kenya.

IV. Potential risks to participants from involvement in the Research Study (if greater than that encountered in everyday life)

No risks identified.

V. Advice as to arrangements to be made to protect confidentiality of data, including that confidentiality of information provided is subject to legal limitations

I wish to let you know that all information that you provide will be used for the purpose of this study only and that it will be treated with strict confidentiality.

Participant data will be anonymised. This means that your name and the name of your school will not be included in any reports. The information will be stored electronically in a research database that only the researcher will have access to.

VI. Advice as to whether or not data is to be destroyed after a minimum period

The participant data will be destroyed within 12 months of the conclusion of the doctoral dissertation.

VII. Statement that involvement in the Research Study is voluntary

Participation in the research study is **voluntary**.
If you decide to take part in this study you will need to sign the informed consent form. You are free to withdraw from the research study at any time until you submit the questionnaire or complete the focus group discussion.

You do not need to give a reason if you decide to withdraw. Your participation and coursework in SIPSE will not be affected in any way, whether you decide to take part in the research or if you decide to withdraw at any time.
If you have any questions concerning this study please feel free to contact me. If I am not available I will get back to you as soon as possible.

Contact: Mary Hooker; Email: mary.hooker@gesci.org; Office: +254 20 3746060/1/2; Mobile: +447748454144

Informed Consent Form

I. Research Study Title

You are invited to take part in a research study to evaluate the use of ICT to support teacher development and classroom practice in the SIPSE project.

The study has the title: A Study of SIPSE Initiative for the preparation of Science, Technology, English and Mathematics (STEM) Science, Technology, English and Mathematics teachers in Kenya and Tanzania to integrate ICT in teaching and learning.

Researcher: Mary Hooker, email: mary.hooker@gesci.org

II. Clarification of the purpose of the research

It is intended that the research will inform how ICT can be used as an instructional tool in the teaching and learning of Science, Technology, English and Mathematics (STEM) subjects in secondary schools in Kenya and Tanzania.

III. Confirmation of particular requirements as highlighted in the Information Statement

Please complete the following – circle Yes or No for each question:

For teachers

I have read the attached information statement	*Yes/ No*
I understand the information provided	*Yes/ No*
I am aware that my data from the SIPSE course will be used	*Yes/ No*
I understand that the research will be published as a Doctoral dissertation	*Yes/ No*

For head teachers

I have read the attached information statement	*Yes/ No*
I understand the information provided	*Yes/ No*
I understand that the research will be published as a Doctoral dissertation	*Yes/ No*

IV. Confirmation that participation is voluntary

I understand that participation is voluntary and that I am free to withdraw my consent at any time until submission of the questionnaires and if invited to participate in interviews or focus group discussions until completion of the interviews and focus group discussions.

V. Advice as to arrangements to be made to protect confidentiality of data, including that confidentiality of information provided is subject to legal limitations

I understand that the data held about me will be anonymised

VI. Any other relevant information

I understand that my involvement / non-involvement in the study will not affect my on-going participation and assessment in SIPSE

Signature

I have read and understood the information in this form. I have a copy of the consent form and contact information of the researcher should I wish to raise any questions or concerns about the research. Therefore, I consent to take part in this research study.

Signature: ____

Name in Block Capitals: ____

Date: ____

Informed Consent Form

Focus Group Discussion with Audio Recordings

All of the focus group discussions will be conducted by the researcher with field note records and audio recording. If you do not wish to be audio recorded, the focus group discussions will be conducted without audio. If you do not wish certain parts of the focus group discussion to be audio recorded, the audio can be switched off for these parts.

The focus group discussion field notes will be written up for the research, without identifying the speakers. Part of the focus group discussion audio recording will be transcribed to written form, without identifying the speakers. The field notes and audio recording will be erased when the research dissertation has been competed, not later than 6 months after completion.

Please tick the following boxes to indicate whether or not you have read the information and understand how you will be invited to participate in the research focus group discussions:

☐ I understand that participation in the focus group discussions is voluntary and that I am free to withdraw my consent at any time until completion of focus group discussions

☐ I understand that all the information gathered in the focus group discussions will be kept strictly confidential and that my name and the name of my school will not be included in any reports.

☐ I understand that the focus group discussions can be audio recorded and I am free to withdraw my consent to be audio recorded

☐ I understand that I may ask that the recorder be turned off at any point during the focus group discussion if there is something that I do not want recorded.

Please tick one of the following boxes to indicate whether or not you agree to taking part in the research focus group discussions:

☐ I **AGREE** to taking part in the research focus group discussions

☐ I **DO NOT AGREE** to taking part in the research focus group discussions

Please tick one of the following boxes to indicate whether or not you agree to taking part in the research focus group discussions with audio recording:

☐ I **AGREE** to taking part in the research focus group discussions with audio recording

☐ I **DO NOT AGREE** to taking part in the research focus group discussions with audio recording

Signature: ________________________ **Date:**______________________
(Name)

Informed Consent Form

Interview with Audio Recordings

All of the interviews will be conducted by the researcher with field note records and audio recording. If you do not wish to be audio recorded, the interviews will be conducted without audio. If you do not wish certain parts of the interview to be audio recorded, the audio can be switched off for these parts.

The interview field notes will be written up for the research, without identifying the speakers. Part of the interview audio recording will be transcribed to written form, without identifying the speakers. The field notes and audio recording will be erased when the research dissertation has been competed, not later than 6 months after completion.

Please tick the following boxes to indicate whether or not you have read the information and understand how you will be invited to participate in the research interviews:

☐ I understand that participation in the interviews is voluntary and that I am free to withdraw my consent at any time until completion of interviews

☐ I understand that all the information gathered in the interviews will be kept strictly confidential and that my name and the name of my school will not be included in any reports.

☐ I understand that the interviews can be audio recorded and I am free to withdraw my consent to be audio recorded

☐ I understand that I may ask that the recorder be turned off at any point during the interview if there is something that I do not want recorded.

Please tick one of the following boxes to indicate whether or not you agree to taking part in the research interviews:

☐ I **AGREE** to taking part in the research interviews

☐ I **DO NOT AGREE** to taking part in the research interviews

Please tick one of the following boxes to indicate whether or not you agree to taking part in the research interviews with audio recording:

☐ I **AGREE** to taking part in the research interviews with audio recording

☐ I **DO NOT AGREE** to taking part in the research interviews with audio recording

Signature: ________________________ **Date:**______________________
(Name)